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# Evaluation of the Problem Posed by In-Place Pollutants in Baltimore Harbor and Recommendation of Corrective Action

Trident Engineering Associates, Inc, Annapolis, Md

Prepared for

Environmental Protection Agency, Washington, D C Office of Water Planning  
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| 16. ABSTRACT<br><br>Previous studies had indicated that Baltimore harbor is heavily polluted. To assess the impact of in-place pollutants on the harbor, the Contractor sampled and analyzed bottom sediments, the water column, and the interstitial water, using bulk sediment analyses, elutriate tests, and bioassays. On the basis of the results of this investigation, it is possible to divide the harbor into four zones; highly toxic, moderately toxic, low toxicity, and slightly toxic. The biota are being stressed by in-place pollutants. Benthic organisms suffer the greatest damage, the intensity varying with the location in the zones of toxicity. Pelagic species are damaged to a lesser extent. Although feasible corrective actions do exist, they would offer only a temporary solution. A permanent solution involves the corrective action plus elimination of pollutant discharges into the harbor.<br><br>A companion report, EPA 440/5-77-015a, contains the appendices and details of the testing and analysis. |                                                                                  |                                          |
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**EVALUATION OF  
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IN BALTIMORE HARBOR  
AND RECOMMEDATION  
OF CORRECTIVE ACTION**



**United States  
Environmental Protection Agency  
Office of Water Planning and Standards  
Washington, D.C. 20460**

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EPA 440/5-77-015B

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and Recommendation of Corrective Action**



**United States  
Environmental Protection Agency  
Office of Water Planning and Standards**

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This study: (1) describes the in-place pollutants within Baltimore Harbor, (2) analyzes the pollutants for their effect upon the environment, (3) investigates potential corrective actions for feasibility and cost, (4) examines the effectiveness and permanence of potential corrective actions, (5) derives conclusions and makes recommendations, and (6) recommends the course of action which is most realistic given the conditions of the Harbor's requirements and use.

Following a comprehensive review of prior related work, a field program was developed and carried out to confirm and extend the results of earlier investigators. In the field program, core borings were taken from twenty sites. Each core was divided into sections to test the levels of concentrations of selected pollutants to depths of 10 feet below the sediment/water interface. The individual samples were analyzed for nine heavy metals, total hydrocarbons by hexane extract, PCB's, and interstitial water metals. In addition, elutriate tests were made, and surface sediments from nine of the twenty sites were used in a bioassay of two finfish and one clam species.

- The analytical techniques used to determine the existence and degree of pollution, such as the bulk sediment analyses, the elutriate tests, interstitial water metal analyses, PCB concentration analyses, and the bioassay did not correlate one with another to indicate pollutants or toxic elements consistently or predictably. The two analytical techniques that did correlate were the bioassay and the sediment analyses for heavy metal, hexane extract, and PCB concentrations. The elutriate test showed that the entire Harbor is classified as polluted, the elutriate being greater than 1.5 times the overlying filtered water metal concentration. Neither the elutriate test nor the interstitial water metal concentration analyses indicated consistent zones of intensity or correlated with the areas known to contain very high levels of toxic materials.
- The biota within the Harbor are being stressed by the in-place pollutants. The benthic organisms suffer the greatest amount of damage, intensity varying according to location within the highly, moderately, low, or slightly toxic zones. The pelagic species are damaged to a much lesser extent. The cause of damage, whether from in-place pollutants or from those presently being discharged, is unknown.

In-place pollutants are a direct result of waste discharges that are incorporated into the sediments. Although the exact quantities and chemical composition of the present discharges are not known, NPDES permit authorizations indicate that significant quantities of heavy metals and total suspended solids are being added to the Harbor each day. The last total inventory of heavy metals and toxic chemicals, published in 1973, showed a daily Harbor influx of 86 tons. Until the goals of P. L. 92-500 are achieved and discharges of toxic materials are greatly reduced or eliminated, any action such as removal of the in-place pollutants would result in but a temporary solution.

- Of the potential corrective actions, "leaving the pollutants in place" is recommended as the preferred choice, at least until the influx of pollutant loads is greatly reduced or eliminated.
- Removal of the in-place pollutants by dredging may be an effective and feasible action to be taken in the future, after the discharge of pollutants has been eliminated. Dredging should be contemplated only after an appropriate amount of time has passed after the elimination of incoming pollutants; natural recovery to the biota of the Harbor may be possible and may well take place through blanketing of the in-place pollutants with clean sediment and natural loss of heavy metals to the water column.
- Placement in a diked disposal area such as the Hart-Miller Island disposal site is feasible and is acceptable under Maryland State law. Costs to dredge and place 79 million cubic yards are estimated at 74 million dollars. To construct a diked disposal site for that quantity of material would cost 54.5 million dollars -- a total estimated expenditure of 128.5 million dollars.

INTRODUCTION AND PURPOSE OF STUDY

The purpose of this study, authorized by EPA Contract Number 68-01-1965, was to perform an "Evaluation of the Problem Posed by In-place Pollution in Baltimore Harbor and Recommendation of Corrective Action Responsive to the Mandate of Section 115 PL 92-500". EPA's statement of work required that:

The Contractor shall furnish the necessary personnel, materials, services, facilities . . . , and otherwise do all things necessary for or incident to the performance of the work set forth below:

- A. The Contractor shall collect and/or generate by measurement, sampling, and analysis, the information necessary to describe the problem area and provide the basis for a viable program of dredging and disposal or other corrective action for Baltimore Harbor, Baltimore, Maryland. The following minimum requirements should be addressed in the study and included in the report:
1. Describe the harbor sediment for its pollutional characteristics, including vertical and horizontal distribution, and the volume of polluted sediment involved in the problem area . . .
  2. Give an analysis of the environmental effect of the polluted sediment and/or why it is a problem (i. e. , can it be left alone, is it part of an area to be dredged, is it adversely affecting water quality and water use? ).
  3. Determine the probable effectiveness and permanence of any corrective action. Will the pollutant sources continue to affect the harbor sediments?
  4. Investigate the various alternative corrective actions and detail their feasibility and cost.

5. Recommend a course of action that is realistic with regards to harbor requirements and use.

Six months were allowed for field work, taking of samples, laboratory work and the preparation of a draft report. To encompass the maximum area of Baltimore Harbor within the allotted time, the field work and the sampling process were designed to build on and supplement prior work which has been performed on the sediments and water column of the Harbor by the authors and by others. Correlation between the findings of the current work and prior work was made wherever possible.

## 2.1 THE AREA INVESTIGATED

In order to evaluate the problem posed by in-place pollutants in Baltimore Harbor, sampling and other work was concentrated in the Harbor area proper. Figure 2-1 shows the general location of Baltimore Harbor and the Chesapeake Bay. Figure 2-2 shows the location of sampling sites used in this investigation along with major sub-divisions of the Harbor and their commonly used names. Since various sources use differing delineations when referring to the segments of Baltimore Harbor, this report follows the map and section names outlined in Villa and Johnson's report for EPA dated January 1974.

# BALTIMORE HARBOR AND VICINITY

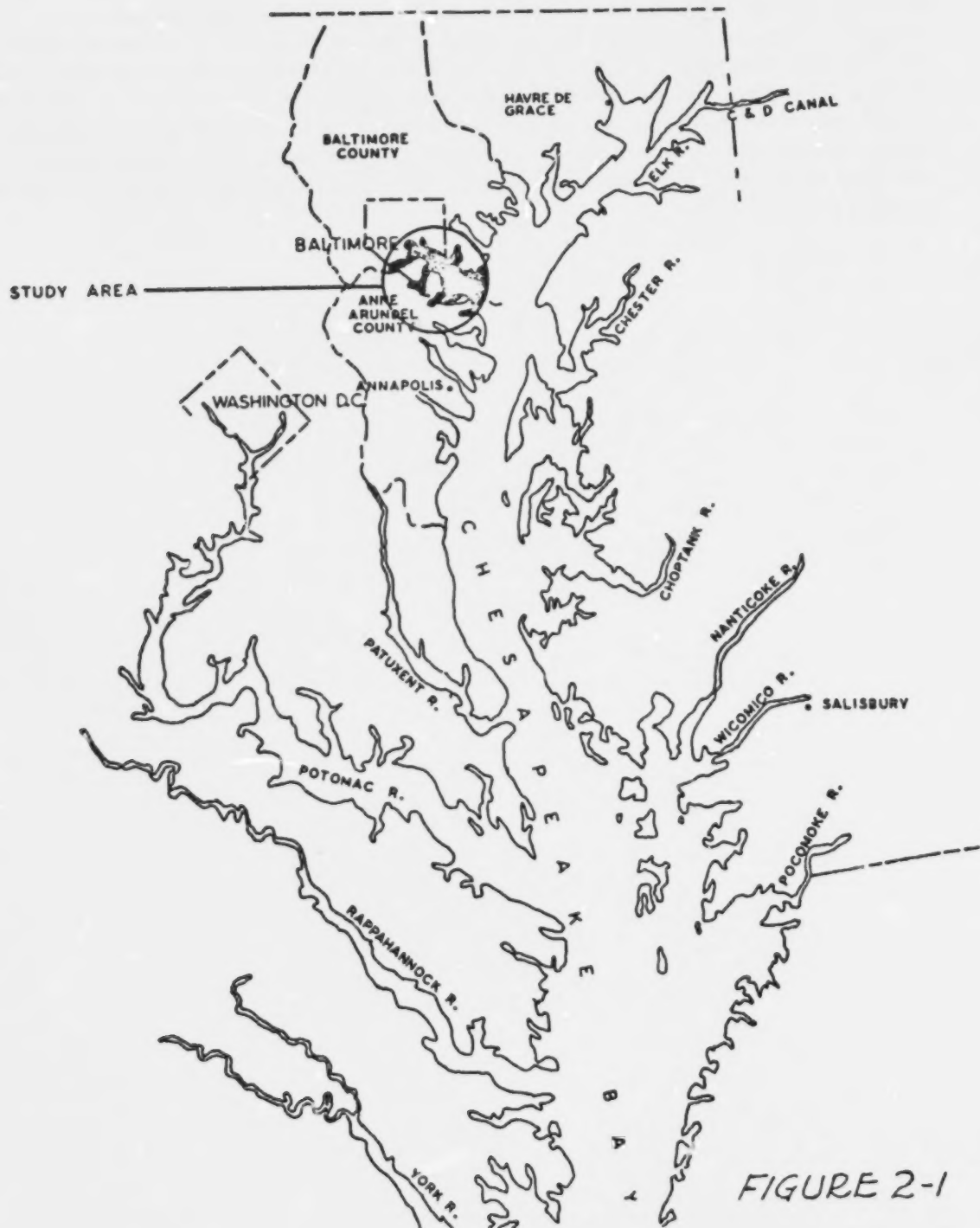


FIGURE 2-1

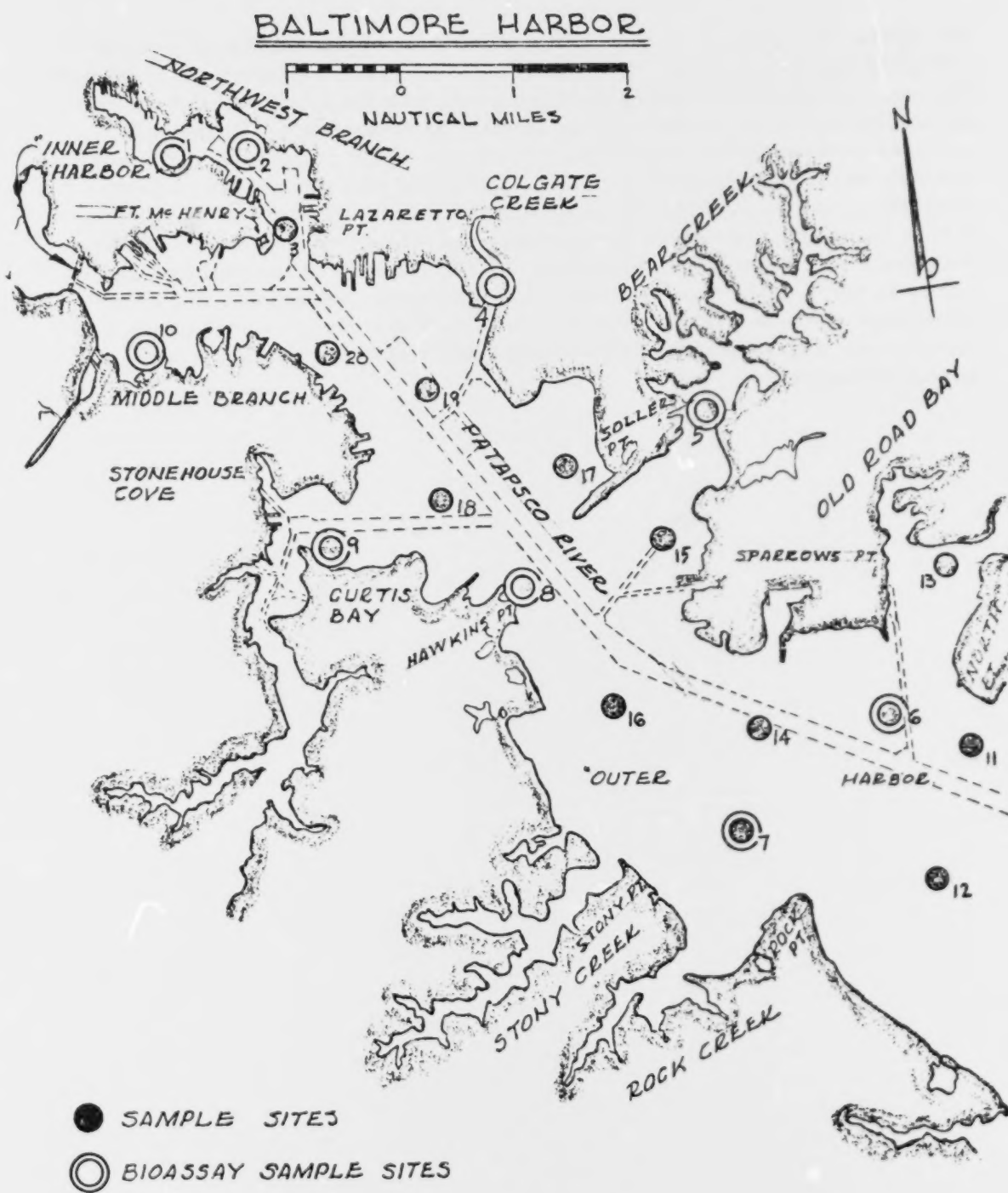


FIGURE 2-2

The initial step was to review and consider for applicability all available published and unpublished work relating to in-place pollutants in Baltimore Harbor. A bottom-sampling field program was then devised and carried out to both confirm and extend the results of prior work. Chemical analyses were made to determine the nature of the pollutants in the core samples and their concentrations. A bioassay was performed to determine the gross toxicity of the in-place sediments. From the work done in this sampling and analysis program, correlated with previous studies, the extent of the vertical and horizontal distribution of the polluted sediments in the Harbor was derived. The technical, economic, and other implications of each potential corrective action were then evaluated, and conclusions and recommendations were derived and a realistic course of action proposed.

To measure the concentrations and distribution of heavy metal and other pollutants present in Baltimore Harbor sediments, twenty sites were chosen for sampling and chemical analysis. Core borings were taken between June 9 - 15, 1976, using the R. V. AQUARIUS, a 65-foot motor vessel belonging to the University of Maryland Center for Environmental and Estuarine Studies. The vessel is fully equipped with modern scientific equipment for conducting research and studies within the Chesapeake Bay and its tributaries. The sampling sites were selected with regard to the location of the main shipping channels and to locations where previous work had been performed. The sites sampled in this study cover the same general areas as those used in the Villa and Johnson study (1974). The sampling and analysis program included the same heavy metals analyzed in the 1974 study. In addition, the investigation added arsenic, hexane extract, PCB's, and an analysis of interstitial water metal concentrations. Also, the standard elutriate test for metal was conducted.

A 15-foot gravity piston corer was used to obtain sediment samples at each of the twenty sampling sites (See Figure 2-2 for locations.). These samples were fractionated into eight layers of individual samples, from 0.16 to 10 feet; and the following analyses were performed:

- ° Sediment Analyses

Analyses were made for percent moisture content; total hydrocarbons by hexane extract; and nine heavy metals: arsenic (As), mercury (Hg), cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn). These were done at each of the eight layers obtained. The individual sample analyses and the procedure used are contained in Appendix C.

- ° Interstitial Water

Samples for interstitial water analyses were obtained from two levels, or depths, of sediment: 5-10 cm and 40-45 cm. The individual analyses and the procedure used to obtain the samples are contained in Appendix C.

- ° Elutriate Test

Samples for the elutriate test were taken from the same eight sediment layers, or depths, of the core as for the sediment analysis and were analyzed for the same nine heavy metals. The individual sample analyses and the procedure used to obtain the samples are contained in Appendix C.

- **PCB Analyses**  
Samples for PCB analyses were obtained from the first four depths of sample material, 0.16, 0.5, 1.0, and 2.0 feet. The results of the PCB analyses and individual sample data are contained in Appendix D.
- **Particle Size and Surface Area Analyses**  
Sediment samples were taken from the top layer at a depth of 0.16 feet and from the bottom layer,  $10.0 \pm 2$  feet. Samples were analyzed for average particle size and specific surface area. The analyses for individual samples is contained in Appendix C.
- **Filtered Water**  
Water samples were obtained at each of the twenty sampling sites. Samples were obtained in three fractions taken from the lower, middle, and upper third of the water depth. The water was then mixed, filtered and analyzed for the nine heavy metals to provide a basis for the chemical analyses of the overlying water fraction in the elutriate test. The analyses for the individual samples and procedure used to obtain the samples are contained in Appendix C.

The results of these chemical analyses and tests provided the basis for describing the in-place pollutants in Baltimore Harbor in terms of their concentration and for their horizontal and vertical distribution as presented in Section 4.2. It also provided a basis for interpretative work in describing the effects of the in-place pollutants contained in Section 5.0. The overall results of interpretative analyses for corrective actions are contained in Sections 6 and 7 and in the Conclusions and Recommendations of this report. Appendix C contains the detailed analyses and individual results of chemical and physical analyses of the samples obtained in the field.

### 3.2 BIOASSAY

At nine pre-selected sites (See Figure 2-2 for locations.) a grab sampler was used to obtain approximately 30 gallons of sediment from the uppermost one foot of bottom material to be used in the bioassay. The procedure used in preparing these samples for the bioassay is contained in Appendix E.

A bioassay was performed using two species of finfish, mummichog, Fundulus heteroclitus, and spot, Leiostomus xanthurus, and one species of clam, Mya arenaria. The purpose of the bioassay was to determine the gross toxicity of the sediments that were taken from several different areas within the Harbor. Previous studies had classified portions of the Harbor as "high," "moderate," "slight," and "low" in toxic effects on the basis of the distribution and abundance of benthic macro-invertebrates. The bioassay, therefore, was designed to indicate relative gross toxicity from one sampling site location to another. The interpretation of the bioassay results are contained in Sections 5.2 and 5.3, and in the Conclusions and Recommendations of this report. The method used for performing the bioassay and specific findings are contained in Appendix E.

From the geochemical and bioassay findings and from engineering studies and reports, all corrective actions having reasonable potential for application were evaluated. These included blanketing, the deposition of layers of plastic material over the polluted bottom sediments to preclude the transfer of the pollutants from the sediments to the water column; inactivation of the polluted sediments by chemical means; and removal of the polluted sediments by dredging. In addition, while not in a sense a corrective action, the effect of leaving the sediments undisturbed also was evaluated. See Sections 6.0 and 7.0 for further discussion.

Each potential corrective action was evaluated with respect to the environment of Baltimore Harbor, which is an active shipping port in a highly industrialized center. The Conclusions and Recommendations of this report reflect a course of action that is considered to be the most realistic with regard to harbor requirements and use and the current and projected future discharges of industrial and community pollutants into the Harbor waters.

#### 4.0 DESCRIPTION OF IN-PLACE POLLUTANTS

#### 4.1 SOURCES AND QUALITY OF DATA AVAILABLE

An extensive literature review was made early in the investigation to both ascertain the extent of current knowledge about pollutants in Baltimore Harbor; and to assist in the design of the field sampling program. In addition, certain proprietary reports and unpublished works were made available to this study, which were helpful. The following is a list of published material reviewed, together with summary comments, pertinent to this study. The reader is cautioned that data formats and data values will be found to differ in these publications. Differing methods for sample preparation, differing analytical methods, differing collection and storage procedures, etc., all combine to modify the final values by factors of 2 to 100 and more (Sommer, 1974, and Bricker, 1975). It will be noted also that no literature could be found which contained information pertaining to heavy metals in interstitial waters or elutriate tests on samples from Baltimore Harbor.

##### Sediment Geochemistry

##### -- Villa and Johnson, 1974, EPA, Region III

The most comprehensive source of sediment geochemical data is by Villa and Johnson. Most of their samples were taken near the surface (5 - 15 cm), 24 of the 176 sites were sampled at 30 - 40 cm depth. These cored samples were analyzed for Pb, Cd, Cr, Cu, Mn, Ni, Zn, and Hg. This study served as the basis for the design of the present report; i. e., techniques and site selection are comparable so that the reports can be compared equitably. The values for the horizontal distribution of the heavy metals from this most recent study (1976) agree in almost every case with the high and low concentrations of the same metals from the same site locations from the Villa and Johnson study.

##### -- Cronin, et al, 1974, Chesapeake Bay Institute and Chesapeake Biological Laboratory

Analyses of Zn, Mn, Cd, Cu, Ni, and Fe, made at 23 sites in the Harbor found large local spatial variations in the metal concentrations. This report found Zn, Cu, and Cd levels to be much higher in the Harbor than in the Bay, 4 to 14 times the maximum levels found in the Upper Bay. The maximum concentrations of Mn, Fe, and Ni were found to be less in the Harbor than in the Bay.

- Biggs, 1968, Chesapeake Biological Laboratory  
Biggs analyzed for Cu, Pb, Zn, Cd, and Cr in sediment samples taken from the Harbor in the vicinity of Dundalk Marine Terminal. He found all of these metals to be of higher concentrations than metals in sediments off Poplar Island, a potential dumping area. Cr varied, at Dundalk, from 94 - 423 ppm, Cu from 65 185 ppm, Cd from 2.84 - 15.58 ppm, and Zn from 303 - 2390 ppm for surface samples. Biggs attributed the metal levels to industrial activity and suggested that the metals are concentrated as metal sulfides in the sediment.
  
- Sommer and Diachenko, 1974, Geological Society of America  
This study contains the only data on heavy metals in interstitial water in the Chesapeake Bay.
  
- Koo, 1975, Center for Environmental and Estuarine Studies  
Contains a physical analysis of sediments in the Harbor obtained from a sieve analysis for percentages of sand, clay, and silt for 28 stations. These data indicate a majority of the sediment to be of silt size with the sand fraction becoming important at the mouth of the Harbor.
  
- Per Hall, Pulleritz - Zollman, 1974, Interstate Division of Baltimore City  
This report on construction in Baltimore Harbor contains the only known information on sediment composition to depths of 80 feet and includes 16 components, many of which are not covered in any other available report. Sediment samples taken from very deep corings and analyzed for heavy metals may indicate possible natural background levels which would be of interest in establishing standards for pollution levels.
  
- Green Associates and Trident Engineering Associates, 1970, Maryland Department of General Services  
This report contains abundant information on comparative chemical extraction techniques applied to sediments and a comprehensive study of the dredged spoil disposal problem. Potential disposal areas from the mouth of the Susquehanna River to Tangier Island were investigated. The chemical and physical characteristics of the channel bottom sediments were examined as were the pertinent characteristics of the movement of the waters in Chesapeake Bay. Preliminary designs were made for containments at the five sites having the greatest overall potential as diked disposal areas.

## Biota

- H. T. Pfitzenmeyer under Koo, 1975, Center for Environmental and Estuarine Studies  
H. T. Pfitzenmeyer briefly reviewed literature pertaining to the biology of Baltimore Harbor prior to 1971. He stated that natural resources of the Harbor rapidly declined before the turn of the century. In 1884 there were 3,800,000 square yards of oyster bars within the Harbor, northwest of a line from Old Road Bay to Sollers Point. In 1907 the northern limit of all oyster grounds was Rock Point at the entrance to the Harbor. Bottom grounds above Bodkin Point were not recommended for oyster culture.
- Yates, 1913, U. S. Coast and Geological Survey  
Yates made a study of oyster bars in Chesapeake Bay in 1906-1912. No oyster bars were shown for Baltimore Harbor.
- Davis, 1948, Chesapeake Biological Laboratory  
Davis also studied this copperas-polluted area of Curtis Bay and confirmed the Olson, et al, findings, but he found more diatoms present per liter in the polluted area than in the relatively unpolluted area.
- Garland, 1952, Chesapeake Biological Laboratory  
Garland made the first extensive water quality survey of Baltimore Harbor and the Patapsco estuary. He stated that in some seasons of the year fishing was good at the entrance to the Harbor, but within the Harbor fishing and crabbing had diminished during the previous quarter of a century and had virtually stopped. This, he concluded, resulted from waste discharges.
- Hohn and Hellerman, 1966, Transactions of American Micro. Soc.  
Hohn and Hellerman studied diatoms in Lewes-Rehoboth Canal, Delaware, and Chesapeake Bay area of Baltimore. They described four new species from Curtis Bay, a major tributary of the Harbor, in the vicinity of Sleds Point. These were Diploneis hormopunctata, Navicula agmastrata, N. cumvibia and N. taraxa.
- Koo, 1975, Center for Environmental and Estuarine Studies  
Chesapeake Biological Laboratory conducted a comprehensive biological study of Baltimore Harbor in 1970-1971. Four major biological groups were studied: fish eggs and larvae by W. L. Dovel; invertebrate benthos by H. T. Pfitzenmeyer; adult fish by M. L. Wiley; and blue crabs by R. L. Lippson and R. E. Miller. The results were summarized and edited by T. S. Y. Koo.

- Villa and Johnson, 1974, EPA, Region III  
Villa and Johnson studied the heavy metal contamination of Baltimore Harbor sediments. They indicated that heavy metal contamination might be a major contributing factor to the biological deterioration of benthic communities of the Harbor.

#### Water Column Chemistry

- Garland, 1952, Chesapeake Biological Laboratory  
Garland evaluated the water quality in terms of waste disposal, past and present, and projected future usage.
- Stroupe, 1961, Chesapeake Bay Institute  
Stroupe studied the flushing mechanism of the Harbor and its effect on waste discharge and biological conditions.

[These two studies are the standard references to water quality in Baltimore Harbor. However, neither report is truly applicable to this study.]

- Ryan, 1953, Maryland Department of Geology, Mines, and Water Resources  
This major study of the Bay sediments included only three sites that could be considered in the Harbor. These samples were analyzed by conventional sieve and wet techniques for size fractionization. The samples were all over 98 percent silt and clay.

## 4.2 POLLUTANT CONCENTRATIONS AND THEIR HORIZONTAL AND VERTICAL DISTRIBUTION

### 4.2.1 Horizontal Distribution

#### 4.2.1.1 Horizontal Distribution - Sediment Analysis

The pollutants identified and analyzed in this study consisted of nine heavy metals, hexane extract, and PCB's. For ease of reference, the average concentrations of the nine heavy metals and the hexane extract observed at the twenty sampling sites have been summarized in Table 4-1. At each site, the core sample was divided into eight layers of sediment by depth, 0.16, 0.5, 1.0, 2.0, 3.0, 5.0, 7.0, and 10.0 feet to portray the vertical distribution of metal concentrations. The concentration of each metal for each of the eight sample depths was then totaled and averaged. Although an average figure for the eight samples does not represent a precise description of the representative sample, it displays conveniently the variable concentrations from one site location to another and offers an overall view of the horizontal distribution. The individual analysis of the concentration of each metal by depth and site location may be found in the tables in Appendix C.

Table 4-1 shows that most of the highest concentrations of heavy metals and hexane extract occur in Sites 1, 2, and 3, all three of which are located in the Northwest Branch of Baltimore Harbor. (See Figure 2-2 for site locations.) Site 4, located in Colgate Creek, and Site 5, located in Bear Creek, also have high concentrations of heavy metals and hexane extract. All of these sites, containing very high concentrations of pollutants in sediment metal distribution, PCB's, and hexane extract, also contain the highest toxic materials as determined by the bioassay.

Site 9, located in Curtis Bay, and Site 13, in Old Road Bay, also contain relatively high concentrations of heavy metals. The sites located in the upper portions of the Harbor, Northwest Branch, and Middle Branch, and the sites located within the creeks have the majority of high heavy metal, hexane extract, and PCB concentration. (See Table 4-2 for PCB average concentrations.)

TABLE 4-1

AVERAGES\* OF SEDIMENT ANALYSES  
CONCENTRATIONS IN mg/kg

| Site            | Total Hydro-Carbons Hexane Extract | Metals mg/kg |             |            |              |              |              |           |            |              |
|-----------------|------------------------------------|--------------|-------------|------------|--------------|--------------|--------------|-----------|------------|--------------|
|                 |                                    | As           | Hg          | Cd         | Cr           | Cu           | Mn           | Ni        | Pb         | Zn           |
| 1               | 7,539                              | 45           | <u>3.20</u> | 5          | <u>1,115</u> | 426          | 294          | 54        | 99         | 651          |
| 2               | <u>26,295</u>                      | 75           | <u>2.70</u> | <u>11</u>  | <u>1,848</u> | <u>1,235</u> | 331          | <u>88</u> | <u>800</u> | <u>971</u>   |
| 3               | <u>25,922</u>                      | <u>124</u>   | 2.60        | <u>8</u>   | <u>1,037</u> | <u>1,661</u> | 333          | <u>87</u> | <u>941</u> | 921          |
| 4               | 11,889                             | <u>187</u>   | 1.40        | <u>111</u> | 621          | 427          | 419          | 53        | 681        | 724          |
| 5               | <u>12,292</u>                      | 57           | 0.25        | 11         | 926          | 164          | 693          | 56        | 455        | <u>1,712</u> |
| 6               | 1,173                              | 15           | 0.20        | 1          | 76           | 44           | 906          | 40        | 93         | 340          |
| 7 <sup>1</sup>  | 980                                | 26           | 0.19        | 2          | 183          | 61           | 810          | 49        | 113        | 428          |
| 8               | 6,572                              | 100          | 0.78        | 2          | 300          | 164          | 949          | 48        | 148        | 676          |
| 9               | 9,506                              | <u>248</u>   | <u>3.30</u> | 3          | 342          | 291          | 767          | 59        | 467        | 545          |
| 10              | 4,233                              | 62           | 0.66        | 3          | 298          | 196          | 325          | 57        | 147        | 380          |
| 11 <sup>2</sup> | 253                                | 9            | 0.04        | 2          | 23           | 14           | 910          | 42        | 17         | 91           |
| 12              | 363                                | 16           | 0.11        | 1          | 28           | 25           | <u>1,390</u> | 40        | 14         | 197          |
| 13              | 313                                | 15           | 0.80        | 4          | 137          | 74           | 511          | 29        | 406        | <u>1,458</u> |
| 14              | 2,155                              | 26           | 0.52        | 2          | 147          | 80           | 1,180        | 46        | 118        | 466          |
| 15              | 8,463                              | 31           | 0.65        | 6          | 596          | 186          | 558          | 45        | 233        | 961          |
| 16              | 2,011                              | 31           | 0.48        | 2          | 178          | 104          | <u>1,423</u> | 52        | 162        | 466          |
| 17              | 4,233                              | 44           | 0.45        | 2          | 270          | 117          | 917          | 48        | 164        | 477          |
| 18              | 1,918                              | 65           | 0.73        | 3          | 348          | 226          | <u>1,341</u> | 54        | 196        | 726          |
| 19              | 4,791                              | 47           | 0.74        | 3          | 288          | 228          | 796          | 65        | 164        | 661          |
| 20              | 10,606                             | 68           | 1.48        | 3          | 362          | 408          | 417          | 64        | 272        | 478          |

<sup>1</sup>No bottom sample taken<sup>2</sup>No middle or bottom samples taken

≡ Highest concentration

≡ Second highest concentration

— Third highest concentration

\*All figures represent the average of the concentrations for all samples per site.

TABLE 4-2  
AVERAGES<sup>1</sup> OF PCB CONCENTRATIONS

| Site           | Average PCB Concentrations (mg/kg) |
|----------------|------------------------------------|
| 1 <sup>2</sup> | <u>&gt;22.58</u>                   |
| 2              | 1.26                               |
| 3              | <u>1.75</u>                        |
| 4              | 1.36                               |
| 5              | <u>2.17*</u>                       |
| 6              | 0.21***                            |
| 7              | 0.27***                            |
| 8              | 0.25**                             |
| 9              | 0.48                               |
| 10             | 0.59                               |
| 11             | <0.05                              |
| 12             | 0.18***                            |
| 13             | 0.49                               |
| 14             | 0.15**                             |
| 15             | 1.16                               |
| 16             | 0.12*                              |
| 17             | 0.45                               |
| 18             | 0.52                               |
| 19             | 0.37                               |
| 20             | 0.43*                              |

<sup>1</sup> All figures represent the average of the concentrations for all samples per site.

<sup>2</sup> Aroclor 1260 was masking 1248 values so that total values may be substantially higher for this one sample set.

\*Average of three out of four samples.  
One sample below detection limits.

\*\*Average of two out of four samples.  
Two samples below detection limits.

\*\*\*One sample only.  
Three samples below detection limits.

     Highest concentration

     Second highest concentration

     Third highest concentration

The results of the sediment metal analyses correlate well with those of the bioassay. Generally those areas containing high concentrations of heavy metals, PCB's, and hexane extract are also those areas determined as highly toxic from the bioassay. Pollutant concentrations, except for Mn, decrease gradually toward the mouth of the Harbor and the entrance to the Bay. The values for the horizontal distribution of the heavy metals agree in almost every case -- Hg is one exception -- with the high and low concentrations of eight of the same metals reported by Villa and Johnson (1974). This correlation is remarkable considering that dredging, storms, and ship traffic would have left their imprint during the three years between sampling programs. This lack of dispersion may indicate the stability of the metal within the sediment or that industrial output is sufficient to replace quickly any metal concentrations removed or transferred.

#### 4.2.1.2 Horizontal Distribution - Interstitial Water Metal Levels

The analysis of interstitial water was considered vital to this study because of its impact on the evaluation of alternative methods of action. The interstitial water may be the major source of the releasable metals during dredging, and no data existed prior to this study on these fluids in Baltimore Harbor. Interstitial water data are very dependent on the manner in which the sample is collected (Bricker, 1975; Sommer and Diachenko, 1974); great care must be taken in preventing oxidation of anoxic sediments, as iron may precipitate and scavenge or adsorb trace metals out of solution. Sample preparation and analytical techniques are contained in Appendix C.

The distribution of interstitial water concentrations for the nine heavy metals is displayed in Table 4-3 which is an average of the two samples taken from 5-10 cm and 40-45 cm depths of the core. Individual sample analyses for each station are given in Appendix C. The distribution pattern of the first, second, and third highest concentrations depicted in Table 4-3 shows that the horizontal distribution of interstitial water is quite heterogeneous and that it does not correlate with the sediment analyses or the bioassay to define areas or sites of high pollutant concentrations. The concentration of metals in the interstitial water, unlike that in the sediment, does not generally decrease toward the Outer Harbor and the Bay.

TABLE 4-3

AVERAGES<sup>†</sup> OF INTERSTITIAL WATER-METAL  
CONCENTRATIONS IN µg/l

| Site | As          | Hg        | Cd         | Cr         | Cu          | Mn           | Ni           | Pb           | Zn           |
|------|-------------|-----------|------------|------------|-------------|--------------|--------------|--------------|--------------|
| 1    | 34*         | 2         | <2         | <u>186</u> | 16*         | 1,755        | <5           | 88           | 1,055        |
| 2    | <50         | 5         | <25        | 94         | <u>50*</u>  | 1,700        | <75          | 570*         | <u>1,800</u> |
| 3    | 71          | 2         | <25        | 44         | <50         | <u>2,700</u> | 100*         | <290         | 370          |
| 4    | <u>91</u>   | <1        | <2         | <u>97</u>  | 12*         | 1,120        | 5*           | 41           | 165          |
| 5    | <25         | <1        | <2         | <u>256</u> | 10*         | 310*         | <5           | 157          | 87           |
| 6    | <100        | <u>9</u>  | <u>25*</u> | <38        | <u>750*</u> | <u>6,650</u> | 100*         | <u>2,550</u> | <u>3,850</u> |
| 7    | <100        | <u>6</u>  | <u>25</u>  | 38*        | <u>50</u>   | 2,340        | <75          | 360*         | 1,000        |
| 8    | <u>152</u>  | <1        | <2         | 36         | 7*          | 1,275        | <5           | <u>4,535</u> | 210          |
| 9    | 56          | 1*        | <u>22</u>  | 59         | <17         | 220          | <u>915</u>   | <170         | 115          |
| 10   | 59          | <1        | <2         | 45         | 7           | 1,835        | <5           | 193          | 580          |
| 11   | <50         | 3         | <25        | <100       | <u>84*</u>  | <u>3,000</u> | <u>1,500</u> | <500         | 260          |
| 12   | <100        | <2        | 2          | 60         | 27          | 2,115        | 70           | <u>1,650</u> | 435          |
| 13   | <50         | 3         | <25        | <38        | <50         | 855          | <75          | <290         | 305          |
| 14   | <50         | 3         | <25        | <38        | <50         | 385          | <75          | 1,100*       | 865          |
| 15   | <50         | 3         | <25        | 38*        | <50         | 420          | <u>175*</u>  | 360*         | 255          |
| 16   | <100        | <u>11</u> | <u>31*</u> | <38        | <50         | 1,030        | 150*         | 580          | <u>1,150</u> |
| 17   | 50*         | 2         | <25        | <38        | <50         | 1,015        | 75*          | 1,470        | 550          |
| 18   | <u>200*</u> | 2         | <25        | <38        | <50         | 325          | 88           | <290         | 180          |
| 19   | 78          | 3         | <u>25*</u> | 38*        | <50         | 565          | <75          | 290*         | 180          |
| 20   | 67          | 2         | <u>25</u>  | <38        | <50         | 900          | <75          | 290*         | 165          |

\* Single sample, not an average.  
All others below detection limits.

+ All figures represent the average of  
the concentrations for all samples per site.

==== Highest concentration

==== Second highest concentration

==== Third highest concentration

#### 4.2.1.3 Horizontal Distribution - Elutriate Test

The elutriate test (Lee and Plumb, 1974), developed by the Army Corps of Engineers, is used to indicate probable metal release as a result of dredging and disposal operations. This test attempts to determine the amount of toxic metals released into the water column from -- or removed from the water column by -- the sediment. Metals are presumed to have been released from the sediment when their concentrations are higher in the elutriate than in the reference water; conversely, they are presumed to have been removed by the sediment when their concentrations are higher in the original reference water than in the elutriate. The Army Corps of Engineers suggests that concentration of each dissolved metal not exceed 1.5 times its original concentration in the filtered water column (Bricker, 1975).

Table 4-4 shows that the horizontal distribution of heavy metals is heterogeneous with little or no correlation to the metal concentrations found in the sediment and interstitial water analyses, or by the bioassay. Additional discussion on this relationship is contained in Section 5.0, "Effects of In-Place Pollutants."

#### 4.2.1.4 Horizontal Distribution - Bioassay

The bioassay was conducted with sediments from eight sampling sites out of a total of nine. (Site 9 was not completed for all bioassay work due to an extreme change in pH of the sediment. See Appendix E for further discussion.) The bioassay and previous work with the community structure and diversity of benthic macro-invertebrates show a definite division of the horizontal distribution of toxic zones or sites. Generally, the same sampling sites that have high concentrations of heavy metals, PCB's, and hexane extract, as shown in Tables 4-1 and 4-2, are also the sites within the zones of high toxicity determined by the bioassay.

Site 5 in Bear Creek was the most toxic for both the finfish and the clam species of the bioassay. Site 4 in Colgate Creek was the second most toxic for finfish and Site 10, in Middle Branch, the third most toxic. Site 2 in the Northwest Branch was the second most toxic for the clam and Site 1, also in the Northwest Branch, the fourth most toxic. There is a general decrease in toxicity toward the mouth of the Harbor, next to the Bay.

TABLE 4-4

AVERAGES<sup>+</sup> OF ELUTRIATE  
TEST-METAL CONCENTRATIONS IN µg/l

| Site            | As           | Hg       | Cd           | Cr          | Cu           | Mn          | Ni           | Pb   | Zn         |
|-----------------|--------------|----------|--------------|-------------|--------------|-------------|--------------|------|------------|
| 1               | <25          | <1       | <2           | 15          | 13           | 460         | <5           | 9    | 16         |
| 2               | <u>44</u> ** | <1       | <25          | <38         | <50          | 266         | 125*         | <290 | 31         |
| 3               | 41**         | <1       | <u>28</u> ** | <38         | <50          | 377         | <75          | <290 | 27         |
| 4               | 26           | <1       | <2           | <u>16</u>   | 13           | 413         | <5           | 6    | 37         |
| 5               | <25          | <1       | <2           | 15          | 14           | 513         | <5           | 11   | 43         |
| 6               | 32*          | 1*       | 25*          | <38         | <50          | <u>996</u>  | <u>150</u> * | <290 | <u>117</u> |
| 7 <sup>1</sup>  | 33**         | 1*       | <25          | <38         | <50          | <u>1030</u> | <75          | <290 | 55         |
| 8               | <25          | <1       | <2           | 15          | 5            | 519         | <5           | 7    | 39         |
| 9               | <u>50</u> *  | <u>1</u> | <u>16</u>    | 34*         | 13**         | 90          | <u>176</u>   | <290 | 36         |
| 10              | 44*          | <1       | <2           | 15          | 6            | 260         | <5           | 9    | 54         |
| 11 <sup>2</sup> | <u>49</u>    | 1*       | 10           | <u>49</u>   | 17           | 563         | <u>235</u>   | <290 | <u>78</u>  |
| 12              | <25          | <1       | <2           | 14          | 19           | <u>670</u>  | <5           | 8    | 37         |
| 13              | 30*          | 1*       | <25          | <38         | 50*          | 206         | 100**        | <290 | <u>68</u>  |
| 14              | 32*          | <1       | <25          | <38         | 50*          | 550         | 88**         | <290 | 27         |
| 15              | <25          | <1       | 25*          | <38         | <u>66</u>    | 350         | 75**         | <290 | 51         |
| 16              | <25          | <1       | 25**         | <38         | <50          | 496         | 100          | <290 | 36         |
| 17              | <25          | <1       | 25**         | <38         | <u>50</u> *  | 564         | 88**         | <290 | 27         |
| 18              | 25*          | <1       | <25          | <38         | <u>67</u> ** | 423         | 100*         | <290 | 22         |
| 19              | <25          | <1       | <u>41</u> ** | <38         | <50          | 303         | 75**         | <290 | 38         |
| 20              | 25*          | <1       | 25*          | <u>38</u> * | <50          | 221         | 75**         | <290 | 33         |

\* Single sample, not an average.  
All others below detection level.

\*\* Two samples only. All others below detection level.

+ All figures represent the average of the concentrations of all samples per site.

<sup>1</sup> No bottom sample taken.

<sup>2</sup> No middle or bottom samples taken.

       Highest concentration

       Second highest concentration

       Third highest concentration

#### 4.2.2 Vertical Distribution

##### 4.2.2.1 Vertical Distribution-Sediment Analysis

It would be difficult to graphically display pollutant concentrations from twenty sites, each containing a core sample divided into eight levels and analyzed for nine heavy metals and hexane extract at each of the eight depths. Thus, the eight samples per site were averaged into three layers: the top layer consisting of the three samples from 0.16, 0.5, and 1.0 feet; middle layer of 2.0, 3.5, and 5.0 feet; and the bottom layer of 7.0 and 10.0 feet (see Table 4-5). This reduces the vertical distribution to three columns of figures instead of eight and also nearly represents the homogeneous concentrations of the top, middle, and bottom layers that would be of interest if removal by dredging were contemplated for depths of 1.0, 5.0, or 10 feet.

Table 4-5 shows a general major decrease in most metals, hydrocarbons, and moisture content at the sub-surface depth of about 5 ft.  $\pm$  2 ft. [5 ft.  $\pm$  2 ft. (corrected core depths utilizing Piggot's (1941) correction factors, due to compaction, would change core depths by approximately +0.30 - 0.9 ft. from 1 to 10 ft; 5  $\pm$  2 ft. would then read 5.5  $\pm$  2 ft.)]

There are some exceptions where the bottom layer contains concentrations higher than found in the upper two layers, e.g., Site 3 in the Northwest Branch for Hg and Pb; Site 4, 5, and 8 for Mn; Site 9 in Curtis Bay for As, Hg, Cu, and Pb; Site 10 in Middle Branch for As and Mn; and Sites 15, 16, and 18 for Mn. The vertical distribution of concentrations shows the same general trend as horizontal distribution -- a decreasing concentration of heavy metals except for Mn toward the mouth of the Harbor.

##### 4.2.2.2 Vertical Distribution - Interstitial Water Metal Levels

Because the sampling for interstitial water was taken from depths of only 5-10 cm and 40-45 cm, vertical distribution is limited to interpretation for variations or consistencies within a narrow range. The individual sample results are contained in the tables of Appendix C for the twenty sampling sites. These data indicate that maximum concentrations are very often found at the lowest core interval, probably indicating a gradient increasing with depth. The sites with the highest levels are on the western side of the Harbor. Pb and Cu are highest near the Bay mouth; Ni, Cd, and As

TABLE 4-5  
AVERAGE CONCENTRATIONS OF  
SEDIMENT ANALYSES FOR CORE SAMPLES

| Trident No.              | Sample Type | Moisture % | Total Hydro-Carbons Hexane Extract mg/kg | Mean Values of Top, Middle, and Bottom Core Sample Chemical Analysis |      |     |       |       |     |     |       |       |
|--------------------------|-------------|------------|------------------------------------------|----------------------------------------------------------------------|------|-----|-------|-------|-----|-----|-------|-------|
|                          |             |            |                                          | Metals mg/kg                                                         |      |     |       |       |     |     |       |       |
|                          |             |            |                                          | As                                                                   | Hg   | Cd  | Cr    | Cu    | Mn  | Ni  | Pb    | Zn    |
| Site 1<br>Top layer      | sediment    | 63.07      | 13,800                                   | 71                                                                   | 4.37 | 8   | 2,177 | 757   | 320 | 67  | 172   | 1,240 |
| Site 1<br>Middle layer   | sediment    | 51.35      | 8,067                                    | 59                                                                   | 5.01 | 5   | 1,037 | 497   | 343 | 56  | 98    | 657   |
| * Site 1<br>Bottom layer | sediment    | 43.70      | 750                                      | 5                                                                    | 0.23 | 1** | 130   | 23    | 220 | 39  | 26    | 56    |
|                          |             |            |                                          |                                                                      |      |     |       |       |     |     |       |       |
| Site 2<br>Top layer      | sediment    | 71.71      | 43,333                                   | 115                                                                  | 4.16 | 20  | 3,400 | 2,300 | 497 | 147 | 1,143 | 1,800 |
| Site 2<br>Middle layer   | sediment    | 61.05      | 35,233                                   | 100                                                                  | 3.91 | 12  | 2,023 | 1,373 | 207 | 79  | 1,243 | 1,043 |
| * Site 2<br>Bottom layer | sediment    | 60.92      | 320                                      | 10                                                                   | 0.11 | 1** | 120   | 31    | 290 | 37  | 13    | 71    |
|                          |             |            |                                          |                                                                      |      |     |       |       |     |     |       |       |
| Site 3<br>Top layer      | sediment    | 58.28      | 29,966                                   | 109                                                                  | 1.40 | 6   | 923   | 2,133 | 320 | 121 | 653   | 780   |
| Site 3<br>Middle layer   | sediment    | 63.81      | 19,600                                   | 146                                                                  | 2.75 | 9   | 1,467 | 1,500 | 343 | 70  | 910   | 1,228 |
| Site 3<br>Bottom layer   | sediment    | 58.22      | 28,200                                   | 118                                                                  | 3.67 | 8   | 720   | 1,350 | 335 | 71  | 1,260 | 55    |

Core Depths

Top layer - 0.16, 0.5, 1.0 feet

Middle layer - 2.0, 3.0, 5.0 feet

Bottom layer - 7.0, 10.0 feet

\* Single sample

\*\* Average figure contains one or more sample analyses where detection limit has been used as the concentration.

Continued ...

TABLE 4-5 (Continued)

| Mean Values of Top, Middle, and Bottom<br>Core Sample Chemical Analysis |                |               |                                                          |              |        |     |       |         |       |    |       |       |
|-------------------------------------------------------------------------|----------------|---------------|----------------------------------------------------------|--------------|--------|-----|-------|---------|-------|----|-------|-------|
| Trident<br>No.                                                          | Sample<br>Type | Moisture<br>% | Total<br>Hydro-<br>Carbons<br>Hexane<br>Extract<br>mg/kg | Metals mg/kg |        |     |       |         |       |    |       |       |
|                                                                         |                |               |                                                          | As           | Hg     | Cd  | Cr    | Cu      | Mn    | Ni | Pb    | Zn    |
| Site 4<br>Top layer                                                     | sediment       | 70.60         | 16,267                                                   | 111          | 1.11   | 84  | 813   | 580     | 333   | 64 | 620   | 1,510 |
| Site 4<br>Middle layer                                                  | sediment       | 65.01         | 16,900                                                   | 419          | 2.74   | 229 | 910   | 640     | 383   | 62 | 963   | 283   |
| * Site 4<br>Bottom layer                                                | sediment       | 46.34         | 2,500                                                    | 30           | 0.28   | 20  | 140   | 61      | 540   | 32 | 460   | 380   |
|                                                                         |                |               |                                                          |              |        |     |       |         |       |    |       |       |
| Site 5<br>Top layer                                                     | sediment       | 78.08         | 33,066                                                   | 111          | 0.56   | 29  | 2,467 | 403     | 380   | 82 | 1,107 | 4,333 |
| Site 5<br>Middle layer                                                  | sediment       | 60.25         | 3,410                                                    | 40           | 0.18** | 3** | 217   | 78      | 600   | 48 | 238   | 716   |
| * Site 5<br>Bottom layer                                                | sediment       | 56.91         | 400                                                      | 21           | 0.02** | 1** | 95    | 121,100 |       | 37 | 19    | 86    |
|                                                                         |                |               |                                                          |              |        |     |       |         |       |    |       |       |
| Site 6<br>Top layer                                                     | sediment       | 57.42         | 2,913                                                    | 27           | 0.47   | 2   | 130   | 104     | 840   | 70 | 251   | 847   |
| Site 6<br>Middle layer                                                  | sediment       | 58.25         | 260**                                                    | 9            | 0.06   | 1** | 54    | 14      | 1,003 | 21 | 14    | 84    |
| * Site 6<br>Bottom layer                                                | sediment       | 49.49         | 345                                                      | 10           | 0.07   | 1** | 43    | 14      | 875   | 30 | 13**  | 87    |

Core Depths

Top layer - 0.16, 0.5, 1.0 feet  
 Middle layer - 2.0, 3.0, 5.0 feet  
 Bottom layer - 7.0, 10.0 feet

\* Single sample

\*\* Average figure contains one or more sample analyses where detection limit has been used as the concentration.

Continued ...

TABLE 4-5 (Continued)

| Trident No.              | Sample Type | Moisture % | Total Hydro-Carbons Hexane Extract mg/kg | Mean Values of Top, Middle, and Bottom Core Sample Chemical Analysis |      |     |     |     |       |    |       |       |
|--------------------------|-------------|------------|------------------------------------------|----------------------------------------------------------------------|------|-----|-----|-----|-------|----|-------|-------|
|                          |             |            |                                          | Metals mg/kg                                                         |      |     |     |     |       |    |       |       |
|                          |             |            |                                          | As                                                                   | Hg   | Cd  | Cr  | Cu  | Mn    | Ni | Pb    | Zn    |
| Site 7<br>Top layer      | sediment    | 61.85      | 1,800                                    | 40                                                                   | 0.34 | 2   | 313 | 108 | 900   | 74 | 215   | 787   |
| Site 7<br>Middle layer   | sediment    | 42.58      | 160**                                    | 11                                                                   | 0.04 | 1** | 52  | 13  | 720   | 24 | 11**  | 68    |
|                          |             |            |                                          |                                                                      |      |     |     |     |       |    |       |       |
| Site 8<br>Top layer      | sediment    | 67.99      | 11,600                                   | 121                                                                  | 0.71 | 4   | 653 | 200 | 680   | 55 | 330   | 1,147 |
| Site 8<br>Middle layer   | sediment    | 65.30      | 6,167                                    | 158                                                                  | 1.37 | 2   | 207 | 242 | 647   | 55 | 81    | 760   |
| * Site 8<br>Bottom layer | sediment    | 54.23      | 1,950                                    | 20                                                                   | 0.25 | 1   | 39  | 51  | 1,520 | 35 | 32**  | 120   |
|                          |             |            |                                          |                                                                      |      |     |     |     |       |    |       |       |
| Site 9<br>Top layer      | sediment    | 77.49      | 5,467                                    | 68                                                                   | 0.73 | 3   | 357 | 283 | 1,573 | 80 | 192** | 697   |
| Site 9<br>Middle layer   | sediment    | 69.27      | 12,500                                   | 110                                                                  | 2.54 | 3   | 333 | 270 | 323   | 44 | 393   | 453   |
| * Site 9<br>Bottom layer | sediment    | 65.19      | 10,550                                   | 566                                                                  | 6.64 | 2   | 336 | 321 | 405   | 52 | 815** | 486   |

Core Depths

Top layer - 0.16, 0.5, 1.0 feet

Middle layer - 2.0, 3.0, 5.0 feet

Bottom layer - 7.0, 10.0 feet

\* Single sample

\*\* Average figure contains one or more sample analyses where detection limit has been used as the concentration.

Continued ...

TABLE 4-5 (Continued)

| Mean Values of Top, Middle, and Bottom<br>Core Sample Chemical Analysis |                |               |                                                          |              |        |    |     |     |       |    |      |     |
|-------------------------------------------------------------------------|----------------|---------------|----------------------------------------------------------|--------------|--------|----|-----|-----|-------|----|------|-----|
| Trident<br>No.                                                          | Sample<br>Type | Moisture<br>% | Total<br>Hydro-<br>Carbons<br>Hexane<br>Extract<br>mg/kg | Metals mg/kg |        |    |     |     |       |    |      |     |
|                                                                         |                |               |                                                          | As           | Hg     | Cd | Cr  | Cu  | Mn    | Ni | Pb   | Zn  |
| Site 10<br>Top layer                                                    | sediment       | 56.83         | 5,600                                                    | 42           | 0.57   | 4  | 467 | 207 | 317   | 73 | 173  | 583 |
| Site 10<br>Middle layer                                                 | sediment       | 50.83         | 4,000                                                    | 50           | 0.75   | 3  | 227 | 220 | 237   | 51 | 139  | 337 |
| * Site 10<br>Bottom layer                                               | sediment       | 46.36         | 3,100                                                    | 93           | 0.66   | 1  | 200 | 160 | 370   | 48 | 130  | 220 |
|                                                                         |                |               |                                                          |              |        |    |     |     |       |    |      |     |
| Site 11<br>Top layer                                                    | sediment       | 49.53         | 253**                                                    | 9            | 0.04   | 2  | 23  | 14  | 910   | 42 | 17** | 91  |
|                                                                         |                |               |                                                          |              |        |    |     |     |       |    |      |     |
| Site 12<br>Top layer                                                    | sediment       | 58.13         | 750**                                                    | 18           | 0.16   | 1  | 44  | 40  | 1,610 | 44 | 19** | 333 |
| Site 12<br>Middle layer                                                 | sediment       | 58.72         | 290**                                                    | 17           | 0.13** | 1  | 29  | 25  | 1,230 | 44 | 12** | 170 |
| Site 12<br>Bottom layer                                                 | sediment       | 59.01         | 50**                                                     | 12           | 0.05** | 1  | 12  | 9   | 1,330 | 32 | 10** | 88  |

## Core Depths

Top layer - 0.16, 0.5, 1.0 feet

Middle layer - 2.0, 3.0, 5.0 feet

Bottom layer - 7.0, 10.0 feet

\* Single sample

\*\* Average figure contains one or more sample analyses where detection limit has been used as the concentration.

Continued ...

TABLE 4-5 (Continued)

| Trident No.             | Sample Type | Moisture % | Total Hydro-Carbons Hexane Extract mg/kg | Mean Values of Top, Middle and Bottom Core Sample Chemical Analysis |      |     |       |     |       |    |       |       |
|-------------------------|-------------|------------|------------------------------------------|---------------------------------------------------------------------|------|-----|-------|-----|-------|----|-------|-------|
|                         |             |            |                                          | Metals mg/kg                                                        |      |     |       |     |       |    |       |       |
|                         |             |            |                                          | As                                                                  | Hg   | Cd  | Cr    | Cu  | Mn    | Ni | Pb    | Zn    |
| Site 13<br>Top layer    | sediment    | 59.09      | 713                                      | 35                                                                  | 2.32 | 9   | 333   | 200 | 1,166 | 54 | 1,197 | 4,267 |
| Site 13<br>Middle layer | sediment    | 43.57      | 127**                                    | 7                                                                   | 0.05 | 1** | 44    | 12  | 193   | 17 | 12**  | 58    |
| Site 13<br>Bottom layer | sediment    | 40.80      | 100**                                    | 4                                                                   | 0.04 | 1** | 34    | 10  | 175   | 16 | 10**  | 48    |
|                         |             |            |                                          |                                                                     |      |     |       |     |       |    |       |       |
| Site 14<br>Top layer    | sediment    | 58.69      | 2,767                                    | 27                                                                  | 0.65 | 2   | 190   | 99  | 1,340 | 53 | 97    | 467   |
| Site 14<br>Middle layer | sediment    | 58.96      | 3,467 **                                 | 40                                                                  | 0.57 | 3   | 203   | 125 | 950   | 52 | 237   | 833   |
| Site 14<br>Bottom layer | sediment    | 54.35      | 230                                      | 11                                                                  | 0.33 | 1** | 48    | 16  | 1,250 | 32 | 20    | 97    |
|                         |             |            |                                          |                                                                     |      |     |       |     |       |    |       |       |
| Site 15<br>Top layer    | sediment    | 63.81      | 21,333                                   | 63                                                                  | 1.27 | 13  | 1,400 | 447 | 610   | 66 | 553   | 2,300 |
| Site 15<br>Middle layer | sediment    | 53.54      | 3,617                                    | 23                                                                  | 0.46 | 4   | 330   | 104 | 203   | 36 | 123   | 483   |
| Site 15<br>Bottom layer | sediment    | 53.88      | 440                                      | 7                                                                   | 0.23 | 1   | 58    | 8   | 860   | 33 | 22    | 99    |

Core Depths

Top layer - 0.16, 0.5, 1.0 feet

Middle layer - 2.0, 3.0, 5.0 feet

Bottom layer - 7.0, 10.0 feet

\* Single sample

\*\* Average figure contains one or more sample analyses where detection limit has been used as the concentration.

Continued ...

TABLE 4-5 (Continued)

| Trident No.             | Sample Type | Moisture % | Total Hydro-Carbons Hexane Extract mg/kg | Mean Values of Top, Middle, and Bottom Core Sample Chemical Analysis |      |     |     |     |       |    |      |       |
|-------------------------|-------------|------------|------------------------------------------|----------------------------------------------------------------------|------|-----|-----|-----|-------|----|------|-------|
|                         |             |            |                                          | Metals mg/kg                                                         |      |     |     |     |       |    |      |       |
|                         |             |            |                                          | As                                                                   | Hg   | Cd  | Cr  | Cu  | Mn    | Ni | Pb   | Zn    |
| Site 16<br>Top layer    | sediment    | 61.47      | 3,900                                    | 38                                                                   | 0.51 | 2   | 275 | 143 | 1,423 | 60 | 170  | 657   |
| Site 16<br>Middle layer | sediment    | 60.58      | 2,033**                                  | 46                                                                   | 0.64 | 2   | 209 | 152 | 1,297 | 59 | 307  | 647   |
| Site 16<br>Bottom layer | sediment    | 58.19      | 100**                                    | 8                                                                    | 0.30 | 2   | 51  | 17  | 1,550 | 37 | 10** | 93    |
|                         |             |            |                                          |                                                                      |      |     |     |     |       |    |      |       |
| Site 17<br>Top layer    | sediment    | 59.32      | 4,800                                    | 39                                                                   | 0.52 | 2   | 353 | 157 | 1,073 | 54 | 187  | 540   |
| Site 17<br>Middle layer | sediment    | 61.04      | 7,800                                    | 81                                                                   | 0.75 | 4** | 420 | 172 | 717   | 48 | 277  | 790   |
| Site 17<br>Bottom layer | sediment    | 54.55      | 100**                                    | 13                                                                   | 0.07 | 1** | 37  | 21  | 960   | 43 | 28   | 100   |
|                         |             |            |                                          |                                                                      |      |     |     |     |       |    |      |       |
| Site 18<br>Top layer    | sediment    | 65.97      | 1,323                                    | 109                                                                  | 1.08 | 5   | 707 | 430 | 493   | 60 | 323  | 1,567 |
| Site 18<br>Middle layer | sediment    | 60.21      | 3,430                                    | 79                                                                   | 1.02 | 2** | 266 | 221 | 980   | 53 | 236  | 514   |
| Site 18<br>Bottom layer | sediment    | 54.51      | 1,000                                    | 8                                                                    | 0.09 | 1** | 70  | 26  | 2,550 | 48 | 29   | 96    |

Core Depths

Top layer - 0.16, 0.5, 1.0 feet

Middle layer - 2.0, 3.0, 5.0 feet

Bottom layer - 7.0, 10.0 feet

\* Single sample

\*\* Average figure contains one or more sample analyses where detection limit has been used as the concentration.

Continued ...

TABLE 4-5 (Continued)

| Mean Values of Top, Middle, and Bottom<br>Core Sample Chemical Analysis |                |               |                                                          |              |      |     |     |     |     |    |     |     |
|-------------------------------------------------------------------------|----------------|---------------|----------------------------------------------------------|--------------|------|-----|-----|-----|-----|----|-----|-----|
| Trident<br>No.                                                          | Sample<br>Type | Moisture<br>% | Total<br>Hydro-<br>Carbons<br>Hexane<br>Extract<br>mg/kg | Metals mg/kg |      |     |     |     |     |    |     |     |
|                                                                         |                |               |                                                          | As           | Hg   | Cd  | Cr  | Cu  | Mn  | Ni | Pb  | Zn  |
| Site 19<br>Top layer                                                    | sediment       | 59.87         | 6,600                                                    | 70           | 0.83 | 4   | 393 | 350 | 817 | 72 | 233 | 937 |
| Site 19<br>Middle layer                                                 | sediment       | 58.14         | 4,473                                                    | 58           | 0.80 | 4   | 310 | 239 | 840 | 77 | 176 | 877 |
| * Site 19<br>Bottom layer                                               | sediment       | 53.32         | 3,300                                                    | 14           | 0.58 | 1   | 160 | 96  | 730 | 45 | 84  | 170 |
|                                                                         |                |               |                                                          |              |      |     |     |     |     |    |     |     |
| Site 20<br>Top layer                                                    | sediment       | 63.59         | 10,667                                                   | 59           | 1.20 | 4   | 503 | 380 | 430 | 70 | 243 | 627 |
| Site 20<br>Middle layer                                                 | sediment       | 55.86         | 13,300                                                   | 96           | 2.10 | 3   | 400 | 440 | 417 | 68 | 393 | 693 |
| Site 20<br>Bottom layer                                                 | sediment       | 53.46         | 7,850                                                    | 48           | 1.13 | 2** | 182 | 403 | 405 | 55 | 179 | 115 |

Core Depths

Top layer - 0.16, 0.5, 1.0 feet

Middle layer - 2.0, 3.0, 5.0 feet

Bottom layer - 7.0, 10.0 feet

\* Single sample

\*\* Average figure contains one or more sample analyses where detection limit has been used as the concentration.

are highest in the center; Cr is high at the head and mouth of the Harbor; and Mn, Zn, and Hg seem to be dispersed throughout the area.

There is little to no correlation in the samples between concentrations of the interstitial metal levels and those found in the sediment analysis and the elutriate test. In general, unlike the sediment analysis and elutriate test, the interstitial water analysis indicates no reduction of concentrations for the sites in the mouth of the Harbor. The relationship between interstitial water and the elutriate test is further discussed in Section 5.0, "Effects of In-Place Pollutants."

#### 4.2.2.3 Vertical Distribution - Elutriate Test

As noted above, the Corps of Engineers' elutriate test standard for consideration of dredging/disposal is that the concentration of a dissolved metal not exceed 1.5 times its original concentration in the filtered water. At all depths of every site sampled, the entire Harbor exceeds this standard for one or more of the heavy metals. Table 4-6 indicates that every heavy metal analyzed (except Pb that was below detection limits) exceeds 1.5 x filtered water in the bottom layer of 7 to 10 feet almost as often as in the top or middle layers. The individual sample concentrations contained in Appendix C show that several of the metals, particularly Mn, increase in concentration with depth of sample.

At no depth of any site sampled is there any correlation in concentrations of heavy metals between those measured by the elutriate test and those found in the bulk sediment analysis. Review of the individual elutriate sample analyses in Appendix C shows that the elutriate exceeds the reference water by as much as 5 and 6 times, e.g., Zn exceeds the filtered water by 5.53 times at Site 13-4 and by 6.66 times at Site 13-3. As seen in Table 4-7, the filtered water concentrations vary only slightly from one site to another. The wide variations of the elutriate could thus not be attributed to variations of the background water. Based on the standard of 1.5 x the filtered water, the results of the elutriate test indicate that the entire 10 feet of sediment sample for every site would be classified as polluted.

TABLE 4-6

**ELUTRIATE TEST ANALYSES  
FOR SAMPLING SITES**

| Site | As  |     | Hg  |     | Cd  |     | Cr  |     | Cu  |     | Mn  |     | Ni  |     | Pb  |     | Zn  |     |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|      | 1.5 | 3.5 | 1.5 | 3.5 | 1.5 | 3.5 | 1.5 | 3.5 | 1.5 | 3.5 | 1.5 | 3.5 | 1.5 | 3.5 | 1.5 | 3.5 | 1.5 | 3.5 |
| 1    | T   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|      | M   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|      | B   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 2    | T   | +   | *   |     | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | +   | *   |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
| 3    | T   | +   | *   |     | +   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | M   | +   | *   |     | +   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
| 4    | T   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|      | M   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|      | B   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 5    | T   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|      | M   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|      | B   |     | *   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 6    | T   | +   | *   |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | M   | *   | *   |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
| 7    | T   | *   |     |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | M   | +   | *   |     | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 8    | T   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
|      | M   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
|      | B   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
| 9    | T   | *   |     | +   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | B   | +   | +   | +   | *   |     | +   |     | *   |     |     |     |     |     |     |     |     |     |
| 10   | T   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
|      | M   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
|      | B   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
| 11   | T   | +   | +   | +   | +   | +   | +   |     |     |     |     |     | +   |     |     |     |     |     |
|      | M   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|      | B   |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 12   | T   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
|      | M   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
|      | B   |     | *   |     |     |     | +   |     |     |     |     |     |     |     |     |     |     |     |
| 13   | T   | +   | *   |     | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | *   | *   | +   | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
| 14   | T   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | B   | +   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
| 15   | T   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   | *   | +   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
| 16   | T   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | *   | *   | *   | +   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | B   | *   | *   | *   | +   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
| 17   | T   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | M   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
| 18   | T   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | M   | +   | *   | *   | *   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
| 19   | T   | *   | *   | *   | +   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | *   | *   | *   | +   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
|      | B   | *   | *   | *   | +   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |
| 20   | T   | *   | *   | *   | *   |     | *   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | M   | +   | *   | *   | *   |     | +   |     | *   |     |     |     | +   |     |     |     |     |     |
|      | B   | *   | *   | *   | +   |     | *   |     | *   |     |     |     | *   |     |     |     |     |     |

1.5 to 3.5 - Range where the elutriate test exceeded 1.5 times the filtered water to 3.5 times or more.

Core Depths

T - Top Layer - 0.16, 0.50, 1.0 feet  
M - Middle Layer - 2.0, 3.0, 5.0 feet  
B - Bottom Layer - 7.0, 10.0 feet

\* Entire site contained samples below detection limits of atomic absorption analyses.

+ Individual samples within a site that contained samples below detection limits of flameless atomic absorption analyses.

TABLE 4-7

METAL CONCENTRATIONS OF  
FILTERED WATER\* IN  $\mu\text{g/l}$

| Site | As | Hg  | Cd | Cr | Cu | Mn  | Ni | Pb  | Zn |
|------|----|-----|----|----|----|-----|----|-----|----|
| 1    | 8  | 0.2 | 8  | 19 | 14 | 380 | 43 | <50 | 20 |
| 2    | 8  | 0.2 | 8  | 17 | 13 | 320 | 36 | 50  | 19 |
| 3    | 8  | 0.2 | 10 | <5 | 17 | 450 | 50 | 50  | 24 |
| 4    | 8  | 0.2 | 8  | <5 | 14 | 410 | 36 | 50  | 39 |
| 5    | 8  | 0.2 | 7  | <5 | 12 | 420 | 47 | 50  | 73 |
| 6    | 8  | 0.2 | 7  | <5 | 14 | 270 | 43 | 50  | 78 |
| 7    | 8  | 0.2 | 9  | <5 | 15 | 410 | 36 | 50  | 32 |
| 8    | 8  | 0.2 | 9  | <5 | 12 | 450 | 36 | 50  | 31 |
| 9    | 8  | 0.2 | 9  | 17 | 11 | 390 | 85 | 50  | 31 |
| 10   | 8  | 0.2 | 9  | <5 | 14 | 360 | 36 | 50  | 24 |
| 11   | 8  | 0.2 | 6  | 38 | 19 | 330 | 94 | 50  | 84 |
| 12   | 8  | 0.2 | 7  | <5 | 12 | 300 | 29 | 50  | 32 |
| 13   | 8  | 0.2 | 6  | <5 | 12 | 90  | 32 | 50  | 15 |
| 14   | 8  | 0.2 | 8  | <5 | 15 | 380 | 36 | 50  | 22 |
| 15   | 8  | 0.2 | 8  | <5 | 15 | 380 | 36 | 50  | 48 |
| 16   | 8  | 0.2 | 8  | <5 | 18 | 450 | 43 | 50  | 23 |
| 17   | 8  | 0.2 | 8  | <5 | 16 | 410 | 36 | 50  | 26 |
| 18   | 8  | 0.2 | 9  | <5 | 17 | 420 | 39 | 50  | 24 |
| 19   | 8  | 0.2 | 10 | <5 | 17 | 540 | 50 | 50  | 30 |
| 20   | 8  | 0.2 | 12 | <5 | 14 | 450 | 50 | 50  | 68 |

\* All figures represent a single sample.

#### 4.3 ESTIMATED QUANTITIES

There are three known sources of data that estimate or list quantities of pollutants discharged into Baltimore Harbor: Helz (1976) surveyed data and estimated quantities of heavy metals that flow into and out of the Harbor; Quirk, Lawler, and Matusky (1973) estimated total tonnages of pollutants being discharged to the Harbor; The National Pollutant Discharge Elimination System (NPDES) permits maintained by the State of Maryland authorize quantities of material for community and industrial discharges.

##### 4.3.1 Helz (1976)

Helz tabulated the metric tons/year of heavy metals entering the northern Chesapeake Bay and the Patapsco Estuary (Baltimore Harbor) (See Table 4-8). He states, "For each metal, the percentage of the total input ascribable to human activities is presented in the bottom line of Table 2 [our Table 4-8]. The figures are for the entire northern Bay system, including the Patapsco. Only industrial discharge, wastewater, storm drainage and the high inputs to the Patapsco from rain and dust have been considered as due to human activities; one exception is Pb for which the rain and dust input to the main stem was also included because most of this is believed to derive from gasoline combustion." An important result of this data inventory was that relatively small percentages of some metals entering Baltimore Harbor remain in Baltimore Harbor. Of the totals entering the Harbor, only the following percentages remain: 76% of Cr, 30% of Mn, 32% of Fe, 10% of Ni, 24% of Cu, 30% of Zn, 21% of Cd, and 35% of Pb (See Table 4-9.) (Helz, 1976).

TABLE 4-8

SOURCES OF HEAVY METALS  
ENTERING BALTIMORE HARBOR  
IN METRIC TONS PER YEAR  
(From Helz 1976 Survey)

|                                                              | Cr  | Mn   | Fe     | Co    | Ni  | Cu  | Zn   | Cd   | Pb  |
|--------------------------------------------------------------|-----|------|--------|-------|-----|-----|------|------|-----|
| Northern Chesapeake Bay<br>Excluding the Patapsco<br>Estuary |     |      |        |       |     |     |      |      |     |
| Rivers                                                       | 70  | 7000 | 70000  | 150   | 300 | 150 | 1000 | 3    | 100 |
| Salt Water Advection                                         | 3   | 20   | 70     | 30    | 100 | 50  | 130  | 5    | 4   |
| Shore Erosion                                                | 23  | 70   | 27000  | 4     | 9   | 8   | 36   | 0.7  | 10  |
| Municipal Wastewater                                         | 20  | 10   | 100    | 0.5   | 5   | 30  | 40   | 2    | 10  |
| Rain                                                         | --  | 20   | 20     | --    | 10  | 90  | 200  | --   | 100 |
| Atmospheric Fallout                                          | --  | --   | --     | --    | --  | --  | --   | --   | 200 |
| Subtotal                                                     | 116 | 7120 | 97190  | 184.5 | 424 | 328 | 1406 | 10.7 | 424 |
| Patapsco Estuary<br>(Baltimore Harbor)                       |     |      |        |       |     |     |      |      |     |
| Rivers and Storm<br>Drainage                                 | 0.5 | 50   | 500    | 1     | 6   | 10  | 70   | 0.02 | 50  |
| Excess Sediment                                              | 4   | 13   | 4200   | 0.7   | 1   | 2   | 4    | 0.07 | 0.9 |
| Municipal Wastewater                                         | 40  | 20   | 200    | 1     | 10  | 60  | 80   | 5    | 20  |
| Rain                                                         | --  | 2    | 7      | --    | 2   | 6   | 30   | --   | 20  |
| Atmospheric Fallout                                          | --  | --   | --     | --    | --  | --  | --   | --   | 50  |
| Direct Industrial<br>Discharge                               | 100 | 440  | 20000  | --    | 58  | 240 | 470  | 1.6  | 76  |
| Subtotal                                                     | 145 | 525  | 24007  | 2.7   | 77  | 318 | 654  | 6.7  | 217 |
| Total                                                        | 261 | 7645 | 122097 | 187   | 501 | 646 | 2060 | 17.4 | 641 |
| Minimum Percent<br>Anthropogenic                             | 63  | 6    | 20     | 1     | 15  | 51  | 29   | 50   | 74  |

TABLE 4-9

PERCENT RETENTION OF TRACE ELEMENTS  
IN ESTUARINE OR COASTAL SEDIMENTS

(From Helz 1976 Survey)

|                                           | <u>Cr</u> | <u>Mn</u> | <u>Fe</u> | <u>Ni</u> | <u>Cu</u> | <u>Zn</u> | <u>Cd</u> | <u>Pb</u> |
|-------------------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Patapsco Estuary                          | 76        | 30        | 32        | 10        | 24        | 30        | 21        | 35        |
| Chesapeake Bay System                     | 68        | 26        | 89        | 16        | 20        | 26        | 22        | 23        |
| Southeastern U. S. Estuaries <sup>1</sup> | -         | 64        | >100      | -         | 22        | -         | 17        | -         |
| World <sup>2</sup>                        | 66        | -         | 29        | 8         | 13        | 44        | 24        | -         |

<sup>1</sup>Windom (in press)

<sup>2</sup>Horn and Adams (1966)

#### 4.3.2 Quirk, Lawler and Matusky (1973)

A second source of data, Quirk, Lawler and Matusky, lists the following substances as being discharged into the Harbor from all sources.

| <u>Substance</u> | <u>Tons/Day (Short Tons)</u> |
|------------------|------------------------------|
| Iron             | 55.5                         |
| Sulfates         | 13.5                         |
| Antimony         | 4.1                          |
| Chlorides        | 3.0                          |
| Tin              | 3.0                          |
| Phenols          | 2.5                          |
| Zinc             | 1.7                          |
| Sulfides         | 0.89                         |
| Arsenic          | 0.82                         |
| Chromium         | 0.78                         |
| Copper           | 0.75                         |
| Total            | 86.4 tons/day                |

#### 4.3.3 National Pollutant Discharge Elimination System Permits

An effort was made during the study to determine the pollutant loads that presently are being discharged into the Harbor. The Maryland State Department of Natural Resources and the EPA regional office in Philadelphia both maintain the same NPDES permit file that lists the individual authorized loadings for both commercial and industrial dischargers and the periodic chemical analyses performed by the industrial dischargers.

Unfortunately, the manner in which both the authorized loadings and the periodic chemical analyses files are maintained in the computer system does not include a program that can be called to summarize or total all factors, or even one column of figures. The file is maintained on a state-wide basis, and to find the discharge authorizations for Baltimore Harbor alone, one would have to manually sort through a computer listing of 423 industries by name under the counties whose watersheds flow into the Harbor and obtain the permit number of those industries.

Once the permit numbers were obtained for those industries located in the Baltimore Harbor watershed, one would have to go to another computer listing that maintains the authorized discharge parameters numerically. To obtain valid data, the permit would also have to be screened to determine whether it was an initial or final authorization. The discharge permitted under a final authorization could be quite different from the initial authorization. Both classifications are printed out on the same computer listing.

In another report format, the actual chemical analyses of the discharges, as recorded by the industry, are reported on an individual basis.

Determination of the loadings authorized by NPDES permit or of the actual loading being discharged into Baltimore Harbor from community and industrial sources was not a task of this project. Since an excessive amount of time would be required to obtain total loadings, and the information, once summarized, would be of questionable value inasmuch as total metal loadings only are reported and these are broken down to individual heavy metals for only a very few industries, further effort in this direction was discontinued.

From the NPDES computer listings, a few of the larger commercial and industrial permit authorizations were totaled to show, as a sample, part of the loadings being, or authorized to be, discharged into Baltimore Harbor. These partial summaries for the month of January 1977 are as follows:

Domestic -- Total suspended solids of 276,816 lbs/day as a weekly average from 47 major sources out of 690 total.

Industrial - Total suspended solids of 879,372 lbs/day maximum from 65 industries out of a total of 184.  
Total metals of 238,378 lbs/day maximum from 9 major industries out of a total of 184.

Although these discharges permitted in 1977 may be considered to be typical at present, the EPA objective is "zero discharge" by 1985. Achievement of the goals of P. L. 92-500 -- "Wherever obtainable... water quality by 1983 will be improved enough to allow for the propagation of fish and for recreation in and on the nation's water... and... by 1985 elimination of all discharges of pollution into navigable waters" -- will eventually eliminate most or all of the pollutants presently being discharged into the Harbor.

The in-place pollutants were evaluated with respect to their effect on the benthos, the pelagic, and planktonic biota of the water column within the Harbor and the biota further afield in the Chesapeake Bay. This division is necessary as it has been found from this study and others that the in-place pollutants in Baltimore Harbor affect these three biological structures in different degrees of intensity and in different manners.

Within this study, the effects upon the benthic and pelagic biota within the Harbor were evaluated from the findings of former studies of the community structure and diversity of benthic macro-invertebrates and from this study's bioassay on finfish and clam species. The bioassay was conducted with sediments from the sampling sites where chemical analyses were conducted for nine heavy metals, hexane extract, PCB's, interstitial water, and the elutriate test. The sections which follow describe the effects of the pollutants on the biota within the limits of the analytical techniques employed and for the toxic elements analyzed.

The commonly used procedure that approximates the sediment-releasable metal level is the elutriate test. The elutriate test results indicate that the sediment has a significant effect on the overlying water column when the sediment is mixed with the water. Every site tested by the elutriate procedure released metals to the water at all core depths in excess of the Corps of Engineers' suggested limit, i. e., 1.5 times the ambient concentration.

The release of metals appears to be very complex and is not explainable by a simple relationship between high sediment-metal concentrations and high elutriate-metal concentrations. Many samples of high metal-pollutant concentrations in the sediment released less metals than those sediment samples of a lower metal content. The pollutant may be partitioned between various mineral components, the interstitial water, and the organic portions in such a way that the effect on the water column by sediment disruption cannot be predicted from bulk chemistry or even from the elutriate test.

Within the limits of this study, one conclusion seems warranted: release of metals contained in the sediment will occur on mixing with the overlying water. Neither the residence time of these metals in the water column nor the per cent of removal from the sediment is known. The release of metals may well be a continuous process. As measured by the elutriate test, the release of metals is approximately 2 - 4 orders of magnitude less than the metal concentration of the sediment levels. This suggests that a sufficient source of metals in the sediment moves to the water over long periods of time (with physical mixing) and returns to the sediment in a new, less-soluble form. This new form of metal pollutant may again be solubilized in the interstitial water or in the sediment at some later date.

Interstitial water-metal concentration analyses often indicate that the concentrations of the metals in the interstitial water are higher than those in the elutriate solutions from which they get their metals. The high levels are much higher than can be accounted for by dilution during the elutriate test (4:1 dilution ratio). Many of these metals are thought to be released from the sediment during the elutriate procedure; the high interstitial (or low elutriate) values may be indicative of oxidation and precipitation during the elutriate analysis, with subsequent loss of dissolved metals for analyses. This interpretation would indicate that the elutriate test, for anoxic sediments, would tend to underestimate the concentrations of those elements that tend to be scavenged or precipitated with hydrous Fe and Mn oxides.

The determination of the effects of in-place pollutants on the biota based on interpretation of sediment and interstitial chemistry is complex and equivocal when one analytical technique is employed as a standard or criteria for quantifications and qualifications of biota toxicity. As reviewed in the preceding sections, the results of the sediment analyses and the elutriate test indicate that, based on the standards established for each analytical technique, the sediments in Baltimore Harbor are polluted.

Quantification of toxicity is difficult to establish when evaluated by an analytical technique that may not be measuring the pollutant available to the organism. In addition, unknown factors such as time relationships of exposure, temperature, pH, salinity, etc. may change or alter the availability of toxic substances to biota in a field condition. While these factors may be measured and controlled in a laboratory experiment, it is extremely difficult to duplicate the conditions to be found in the field. The effects of the in-place pollutants on the benthic and pelagic biota are discussed in the following sections separately.

## 5.2 BENTHOS

Based on the results of former studies of the community structure and diversity of benthic macro-invertebrates and on the results of the bioassay from this study, it is concluded that toxicity may be correlated to a significant degree with the high levels of pollutants contained in the sediments of Baltimore Harbor. The present benthic community structure and diversity reflect the toxicity of in-place pollutants in the sediments. Using gross toxicity as the principal criterion, the sediments in Baltimore Harbor were divided into four toxic zones: highly toxic, moderately toxic, low toxic, and slightly toxic (see Figure 5-1). The criteria and detailed division of these four toxic zones and their relationship to the benthic macro-invertebrates in the Harbor are contained in Appendix E.

### Highly Toxic Zone

The highly toxic zone includes the middle section of the Northwest Branch, Site 2; Colgate Creek, Site 4; Bear Creek, Site 5; Curtis Bay, Site 9; and a part of Inner Harbor (no sample site at this location). In this zone Site 5 was the most toxic, and Sites 2 and 4 were the next most toxic for both finfish and the clam species of the bioassay. (See Figure 2-2 for the location of sampling sites.) In this zone the surface layer of sediments contained high concentrations of PCB (0.64 - 5.60 mg/kg) and hexane extracts (oil and grease) (15,500 - 48,500 mg/kg, except for Curtis Bay where the hexane extracts were 4,200 mg/kg). The bulk concentrations of heavy metals in the sediments were also high, as can be seen in Table 4-1. In this zone the species diversity indexes of benthic organisms were less than 0.69. Only pollution-tolerant Annelida, such as Limnodrilus sp., Heteromastus filiformis, Scolecopides viridis, and Streblospio benedicti were common in this zone. Insecta and Arthropoda were absent or nearly absent.

### Moderately Toxic Zone

The moderately toxic zone includes most of Inner Harbor, Site 10; the upper and lower reaches of Northwest Branch, Sites 1 and 3; and the Patapsco River portion of the Harbor, Sites 16, 17, and 20. In this zone the surface layer PCB and hexane extracts were moderately high, <0.05 - 2.27 mg/kg<sup>1</sup> for the former and from 3,900 to 58,400 mg/kg for the latter.

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<sup>1</sup>The PCB concentration for Site 1 is not included in this range of concentrations as the sensitivity of detection limit was exceeded by a background masking. Therefore, the quantity indicated is probably incorrect.

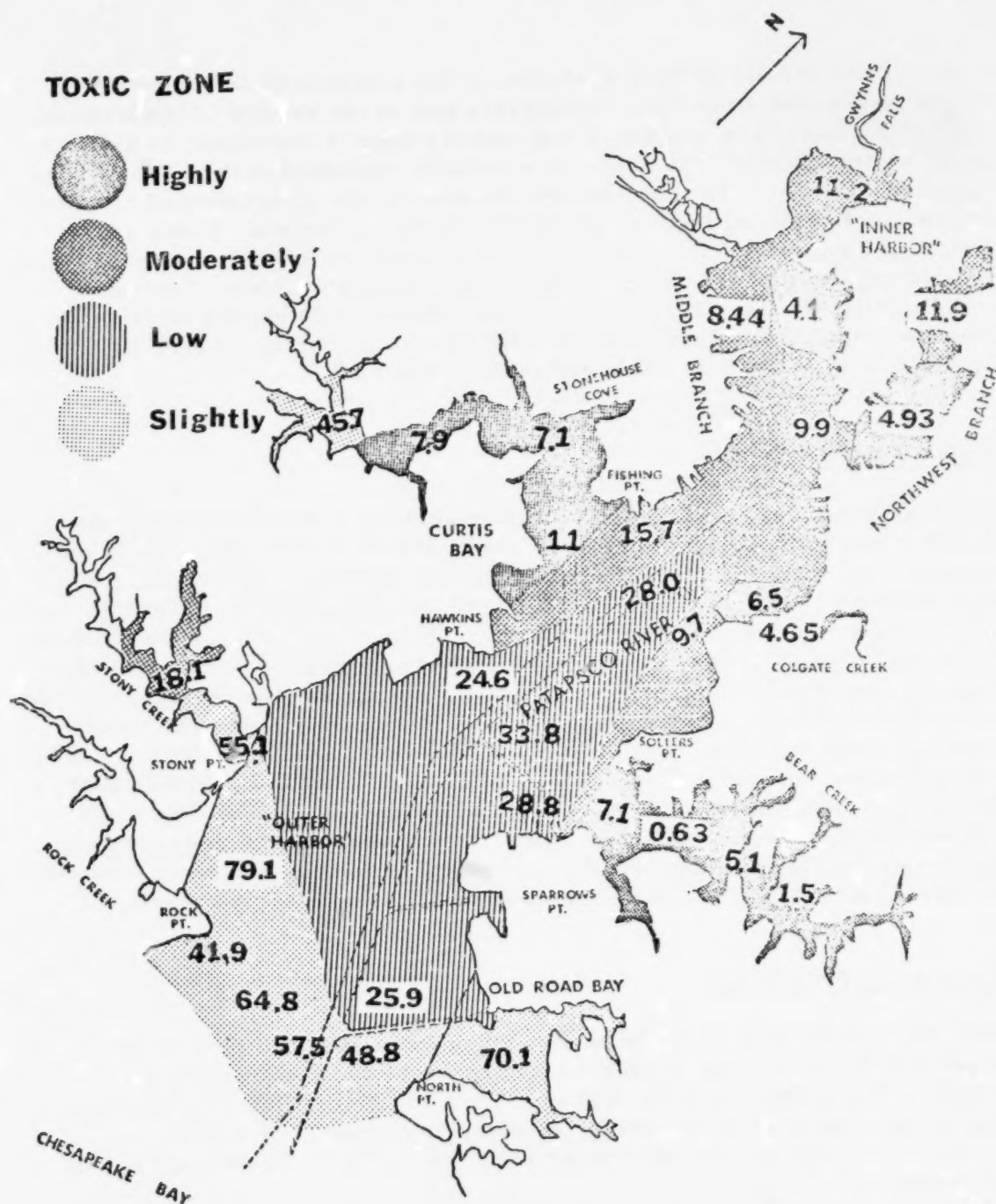


**Figure 5-1** Distribution of toxic zones and mummichog 24-hour TLm values for suspended solids in Baltimore Harbor (numbers in squares, real values obtained from the bioassay; numbers not in square obtained from conversion of species diversity indexes of benthic invertebrates).

Site 1 was the third most toxic for the clam, and Site 10 was the fifth most toxic for clam and the fourth most toxic for finfish. In this zone the species diversity indexes of the benthic macro-invertebrates were between 0.70 - 1.09. The community structure was still dominated by pollution-tolerant Annelida, but a few species of Arthropoda, Insecta, and Mollusca were occasionally present. In addition to those species of Annelida commonly found in the highly toxic zone, one species of Mollusca, Macoma balthica, was fairly abundant in this zone.

#### Low Toxic Zone

The low toxic zone is located in the middle portion of the Harbor, Sites 6, 8, 14, 15, 16, and 19. In this zone, the concentrations of in-place pollutants ranged from 0.11 - 2.32 mg/kg for surface PCB's and from 2400 to 21,000 mg/g for surface hexane extracts. The heavy metal concentrations were generally low except for Mn at Site 16, which was the highest average for all samples. In this zone, Annelida were still a dominant group of the benthic macro-invertebrates, but some species of Insecta, Mollusca, Arthropoda, Coelenterata, and Nemertea were also commonly present. They were represented by Macoma balthica of Mollusca, Rithropanopeus harrisi of Arthropoda, and Micrura leidyi of Nemertea.

#### Slightly Toxic Zone

The slightly toxic zone includes Outer Harbor, Stony Creek, and Old Road Bay, Sites 7, 11, and 12. In this zone the surface concentrations for PCB's and hexane extracts were lowest in the Harbor, less than 0.05 - 0.07 mg/kg for the former and 400 - 2,900 mg/kg for the latter. The average heavy metal concentrations were relatively low, except for Mn at Site 12 where it was the second highest for all sites. The species diversity indexes of the benthic macro-invertebrates were higher than 1.50. Mollusca, Arthropoda and others were as common or as abundant as those pollution-tolerant species of Annelida. In this zone Macoma balthica, Macoma phenax and Rangia cuneata of Mollusca; Leptochierus plumulosus, Cymadusa compta, Corophium lacustre, and Cyathura polita of Arthropoda; and Micrurus leidyi of Nemertea are either as common or as abundant as those pollution-tolerant species of Annelida found in the highly and moderately toxic zones.

The bottom-dwelling and bottom-feeding species of fish which depend on benthic macro-invertebrates as their foods are virtually absent from the entire Harbor. These include winter flounder, Atlantic croaker, and hogchoker which are normally very common in Chesapeake Bay estuaries. These species of fish are affected strongly by in-place pollutants directly and/or indirectly.

In-place pollutants in sediments occur primarily in two forms, particle-associated and dissolved. Their concentrations vary vertically and horizontally in Baltimore Harbor as outlined in Section 4.0. The in-place pollutants in the deep layer of the sediments, which are anaerobic and abiotic, do not seem to directly affect the water quality and biotic life in the Harbor. However, this layer becomes a reservoir for the pollutant which, if sufficiently disturbed, may become available to the biota. The greatest concern in terms of the ecosystem of the Harbor is with the in-place pollutants in the present upper layer of sediments where the benthic organisms live and where these pollutants may be released into the water column.

#### 5.2.1 Interstitial Water Metal Concentrations

Pollutants dissolved in the interstitial water are mobile and chemically active, and it was assumed that the pollutants in this form had a more significant effect on aquatic life than the particle-related forms that are fairly stable. Benthic organisms that live in and on the sediments are in continuous contact with the interstitial water, and they are the organisms to be directly affected by this dissolved form of in-place pollutants in the sediments. On the basis of this consideration, the toxicity level of interstitial water in the Harbor was assessed in accordance with the hazard levels of heavy metals in water for marine organisms suggested by EPA (1973): 0.1 mg/l for Cr, Mn, Ni, and Zn; 0.05 mg/l for As, Cu, and Pb; 0.01 mg/l for Cd; and 0.0001 mg/l for Hg. The concentrations at or exceeding the hazard limits are: As at Site 9; Hg at Sites 1, 2, 6, and 7; Cd at Site 9; Cr at Sites 2, 4, and 5; Cu at Sites 2 and 7; Ni at Sites 6 and 9; and Mn, Pb, and Zn at all sites studied. On the basis of these standards set for hazard levels, the interstitial water in the Harbor sediments at all bioassay sites is hazardous to aquatic life.

Species diversity indexes for benthic macro-invertebrates significantly correlate with the gross toxicity of sediments as determined from the 24-hour TLm value of the Mummichog in the bioassay. (See Appendix E for specific correlation and determinations.) However, the high concentrations of Pb, Cr, Zn, and Mn in interstitial waters from the same sites showed no correlation with the results of the bioassay. Therefore, these heavy metals dissolved in interstitial waters, assumed to be an important factor in biota toxicity, apparently are not the decisive factors determining direct toxicity or, probably, species diversity.

#### 5.2.2 Sediment-Metal Concentration

The bulk concentrations of heavy metals in the Harbor sediments mentioned previously in the toxic zones are much higher than those present in the interstitial water. The average bulk concentrations of heavy metals in the surface layer at the nine bioassay sampling sites are more than those in the interstitial water by the following: 27,481 times for Cu, 4,481 times for Cr, 2,100 times for Zn, 871 times for Pb, 631 times for Ni, and 503 times for Mn. Almost all of the heavy metals in the Harbor sediments are in the particle-related form. Benthic macro-invertebrates live in and on the sediments and may take in these particle-related heavy metals through ingestion or sorptive mechanisms.

Correlation analyses between the gross toxicity of the Harbor sediments and the bulk concentrations of heavy metals in the sediments show that the correlation coefficients are -0.42 for Pb, -0.39 for Cr, -0.21 for Zn, -0.51 for Cd, -0.41 for Hg, -0.18 for Ni, -0.43 for Cu, -0.22 for As, and 0.46 for Mn. All are at insignificant levels, but higher than those for the interstitial water. The heavy metals associated with particles are much more important in causing damaging effects on benthic organisms than those dissolved in water.

#### 5.2.3 PCB's and Hexane Extract Concentrations

PCB's are soluble in oil but only slightly soluble in water. Bulk concentrations in the Harbor sediments at twenty widely distributed sites were all considerably higher than the hazard limit of 0.002 µg/l for freshwater

suggested by EPA (1973). (Marine organisms are much more sensitive to PCB's than freshwater organisms.) Because the PCB analysis for this study was performed from sediment samples only, the concentrations of PCB's in the interstitial water are unknown. Therefore, it is not known if concentrations of PCB's in this medium are hazardous to aquatic life in the water column.

PCB concentrations in the Harbor sediments correlate significantly with hexane extracts, tending to be higher in the surface layer than in the deep layer. Because PCB's are associated mainly with oil and grease, extremely high concentrations of hexane extracts in the Baltimore Harbor sediments suggest correspondingly high concentrations of oil and grease. The benthic organisms living in such sediments will be affected by the oil and grease and the in-place pollutants, PCB's, which they contain. Hexane extracts and PCB's are moderately correlated with the gross toxicity of the Harbor sediments.

Therefore, it appears that those in-place pollutants associated with particles and those pollutants associated with grease and oil in the Harbor sediments are major factors causing damaging effects on the benthic macro-invertebrates and the bottom-dwelling and -feeding fish. These, perhaps in combination with other toxic conditions, adversely affect benthic populations throughout the Harbor to a varying but serious degree.

The community structure, diversity, and distribution of pelagic fish and phytoplankton are much less related to the sediment toxicity than are the benthic macro-invertebrates and bottom-dwelling fish. (See Appendix E for distribution charts.)

The species diversity of fish, particularly those living in shallow shore water, tended to decrease going from the slightly toxic zone to the highly toxic zone; but this trend was not so obvious as that in the benthic invertebrates. Certain species of fish, such as silversides in water near shores, and white perch, rock fish, and alewife in the off-shore water in the Harbor, were common and abundant over all toxic benthic zones. However, some fish had lesions on their skins and fins, indicating the presence of a degree of environmental stress. Planktonic larva and juvenile fishes were fairly evenly distributed in the Harbor regardless of toxic zones. As they feed mainly on planktonic foods, they demonstrate no gross effect from the in-place pollutants in the sediments. It is possible that the in-place pollutants in the sediments are being released into the water column and thus are affecting the water quality and aquatic life since both emigration from the sediments and the effects of resuspension can introduce such pollutants.

It appears that the present community structure, diversity, and distribution of pelagic fish and planktonic organisms may be affected by the pollutants present in the water column as a result of domestic and industrial waste discharges and by those released from the in-place sediments. It is not possible to estimate the relative importance of these two sources.

The highly and moderately toxic zones within Baltimore Harbor depicted in this study are those where in-place pollutants have caused or may potentially cause significant damage to the Harbor ecosystem. The chemical compositions of the in-place pollutants in the Harbor sediments are extremely complicated. There is no single chemical parameter among those examined in this study that can be used to indicate sediment toxicity. There is no way, from the few chemical parameters studied, to know all of the pollutants in the sediments, to predict their toxicity, or to assess their impact on the Harbor ecosystem.

The gross toxicity of the Harbor sediments determined by the bioassay and the biological indicator represented by the species diversity index of the Harbor's benthic macro-invertebrates provides useful information

regarding the total toxicity of the in-place pollutants and their biological effects in Baltimore Harbor. These analytical techniques are considered to be the most accurate in describing areas that may be considered in the future for removal of the sediments that are considered to be highly toxic and where the benthic macro-invertebrates have already been severely damaged. These areas are located in Northwest Branch, Colgate Creek, Bear Creek, Curtis Bay, and a part of Inner Harbor. The moderately toxic zone undoubtedly is also a problem area but less so than the highly toxic.

It is clear from the results of the tests made in this study and from the information derived from previous work that the sediments at the majority of the sites in Baltimore Harbor exceed relevant established criteria for pollutant levels. Given this condition and given the provisions of Section 115, P.L. 92-500<sup>1</sup>, it becomes pertinent to examine the corrective actions which have potential for solving the problem. These, essentially, are four in number, and they are reviewed in Sections 6.1 through 6.4 which follow.

The results of any corrective action applied to in-place pollutants which were deposited over a period of time measured in decades will be but temporary if similar or other pollutants are permitted to be discharged into the Harbor or the tributaries which flow into it. Thus, to fully grasp the effectiveness and permanence of any proposed action, one must first consider the question of the current influx of pollutants to the Harbor and the projected changes and trends in these influxes.

This question is one of overriding importance in understanding the problem in Baltimore Harbor since the Harbor receives effluent from numerous industrial sites and drainage from more than 600 square miles of land area, discharging a mean of 550 cfs of water into the Harbor. It has been estimated that more than 86 tons of contaminants enter the Harbor each day (Quirk, Lawler, and Matusky; 1973). Therefore, any corrective action would soon be made ineffective by the addition of new pollutants replacing those previously removed or otherwise disposed of. The present daily input of pollution must be eliminated or drastically reduced in order to achieve a clean Harbor; else any corrective treatment of the sediments would soon be negated.

The physical circulation pattern in the Harbor is dependent upon phenomena occurring in the adjacent Chesapeake Bay. According to Stroupe, et al, 1961, the primary factor contributing to the renewal of water in Baltimore

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<sup>1</sup>P.L. 92-500, "In-Place Toxic Pollutants", "Sec. 115. The Administrator (EPA) is directed to identify the location of in-place pollutants with emphasis on toxic pollutants in harbors and navigable waterways and is authorized, acting through the Secretary of the Army, to make contracts for the removal and appropriate disposal of such materials from critical port and harbor areas...".

Harbor is a density-induced, three-layered flow pattern. This circulation pattern of the Harbor's water must be taken into consideration when evaluating corrective actions such as dredging and disposal and what effect this action might have on both the Harbor and the Chesapeake Bay waters as a result of the dispersion of polluted sediments into the water column.

Pollutants in the sediments are highly heterogeneous in distribution and concentration, although all twenty sites of the materials sampled are contaminated by criteria of the elutriate test standard of 1.5 times the concentration of the overlying water. Previous observations by EPA and others and the chemical sampling conducted under this program all demonstrate that subsections of the Harbor vary greatly in pollution burden and suggest that highly localized deposits may also exist. It is also clear that wind, tidal action, vessel traffic, and the effects of dredging have dispersed extensively some of the surface sediments and associated chemicals within the Harbor.

In addressing possible corrective actions, the size of the area to be treated or quantities of material to be removed are important considerations. The Harbor is a shallow embayment consisting of approximately 34 square miles of the lower portion of the Patapsco River and ends at a line between North Point and Rock Point. With a mean depth of 15.8 feet, the Harbor contains 15 billion cubic feet of water (Quirk, Lawler, and Matusky; 1973).

Using the elutriate test results to determine which sampling sites contain contaminated material and to what depths, it can be seen from Table 4-6 that all twenty sampling sites contain contaminated sediments. The number of heavy metal contaminants per site varies from two to seven of the nine metals analyzed, and they are distributed at all depths taken in the core samples, from 0.15 to 10.0 feet. These findings indicate that contaminants in the form of one or more of the heavy metals analyzed are present throughout the Harbor at all vertical levels.

If only the areas of higher pollutant concentrations are to be considered for correction, the proper analytic technique to identify these areas must be determined. As mentioned in Section 5.0, the chemical and bioassay analyses performed for the sediments, the interstitial water, and the elutriate test do not correlate to show clear evidence of a definite zonal distribution of pollutants. Within this study, the results of the elutriate test and of the bioassay have been used to define kinds and degrees of contaminated material since these techniques are the only two presently accepted by Federal and State agencies for dredging and disposal considerations.

## 6.1 BLANKETING AS A CORRECTIVE ACTION

A recent development in reducing turbidity during diving and similar operations may prove significant as a corrective action to water pollution. This development, known as blanketing, involves depositing plastic in thin layers over material that might be easily disturbed. The United States Naval Civil Engineering Laboratory in Port Hueneme, California, has experimented with forcing chemicals through a shaped nozzle to form a layer of flexible, nontoxic plastic to seal sediments to the bottom in a working area. Because of the possible advantages of sealing contaminated sediments in place by this method, it was analyzed further to determine its applicability to Baltimore Harbor. Additional information on the process and technique can be found in Appendix F.

### 6.1.1 Effectiveness and Permanence

The success of an effort to seal the contaminated sediments in Baltimore Harbor in place with a plastic layer would depend upon the feasibility of locating the film permanently and avoiding damage by external forces. In considering these problems, the following difficulties emerge:

- ° Ship channel maintenance and improvement dredging would remove the plastic strips from alongside piers, channels, and vicinity of channels;
- ° The screw currents of ship traffic would disrupt the strips of plastic, especially in and near channels. Evidence of the tendency for screw currents to disrupt the bottom can be seen wherever ships' passages leave a trail of increased turbidity. On occasion, ship traffic to certain terminals in Baltimore Harbor may have only a few feet clearance below the hull or may even make contact with bottom muds as an accepted procedure;
- ° Anchoring by vessels of any size, ranging from small pleasure craft up to and including commercial vessels, would defeat the purpose of the plastic layer. Since the effectiveness of an anchor depends upon its ability to dig into the bottom and obtain a purchase, almost every

conceivable anchor would penetrate the plastic layer. Anchors in use on the Harbor range from a few pounds in weight up to 30,000 pounds:

- ° The debris brought into the Harbor by storms can range from the tree stumps and branches brought in by spring freshets to the heavy debris brought downstream by heavier storms like Hurricane Agnes. Much of this debris has the potential to tear and otherwise disrupt a plastic sealant layer on the bottom of the Harbor;
- ° In addition to the disruptive agents cited above, currents in parts of the Harbor would also contribute to disturbing the plastic strips laid on the Harbor bottom. Each of the boundaries of the strips, in addition to any tears or other openings in the plastic, would offer an opportunity for Harbor currents to get under the strip and further disturb its position;
- ° Many modern vessels rely on taking in water through hull openings for the operation of the ship. These openings can be as small as two or three inches or as large as five or six feet in diameter. Blocking such openings with plastic sheeting can put the ship out of operation and cause serious damage to machinery.

In the light of these difficulties, it is concluded that blanketing could be effective only in isolated areas for special applications, out of the normal Harbor traffic patterns and not subject to heavy storm runoff. Of the sites sampled, only one (Site 10), located in the Middle reach area and in relatively shallow water off to the side of the sand bars of the Patapsco River, meets these criteria. However, this site would experience heavy current flows with accompanying debris in the event of another storm comparable to Hurricane Agnes; so, even here, the use of plastic blanketing is questionable.

In view of these considerations, blanketing with a plastic layer is not considered an effective method to correct the problem of contaminated sediments in Baltimore Harbor.

## 6.2 INACTIVATION AS A CORRECTIVE ACTION

Inactivating or neutralizing the toxic materials contained in sediments has not, according to available data, been accomplished in a field situation where millions of square feet of bottom area and multiple chemical compounds are involved. Probably the best known examples of neutralization or inactivation of toxic substances in field conditions are to be found in the treatment of mine drainage spoils. In mine drainage spoil material or acid mine drainage water, various processes or treatments have been used to neutralize or reduce chemical parameters such as pH, acidity, alkalinity, and sulfates and have reduced to acceptable effluent levels compounds of iron, calcium, magnesium, manganese, and aluminum. The processes or treatments are usually specific for individual or specifically known compounds and are applied to the effluent rather than the spoil material. Typically, mine spoil is simply treated with lime to neutralize the acidity and the mine drainage water is then further treated, if necessary, for aquatic life or for potable water uses.

### 6.2.1 Effectiveness and Permanence

Within this study, chemical analyses were performed on samples from sediments, water column, and interstitial water, and for the elutriate test. The analyses show that the sediment samples from all twenty sites and from one or more core depths contain at least two heavy metals that exceed the elutriate test level of 1.5 x the overlying filtered water concentrations. It is highly likely that they contain significant quantities of additional chemical contaminants whose compositions are unknown because they were not analyzed.

Only four sampling sites, numbers 1, 2, 3, and 7 (see Table 4-6) do not contain heavy metal concentrations that exceed the elutriate test in the bottom strata of seven to ten feet of sediment. The depth of containment of the heavy metals analyzed in all the other sites is such that any treatment or inactivation attempted on surface sediments would be relatively ineffective on those contained in lower depths. Due to the volumes and depths of contaminants in the Harbor sediment and improbability of an effective treatment, inactivation of the toxic materials is not considered an effective or permanent corrective method.

The removal of all or part of the sediments considered to be either highly or moderately polluted in Baltimore Harbor is physically possible, although the depths of the contaminants beyond 10 feet are unknown. There are several alternative methods of dredging and a number of theoretically possible alternative receiving sites for disposal of the dredged materials which are contained in detail in the following sections.

#### 6.3.1 Volumes to be Removed

The depth to which Baltimore Harbor would have to be dredged to be able to reach an "uncontaminated" stratum is unknown. In this study, the elutriate test was used to determine when heavy metal concentrations exceeded the established criteria and could be called "contaminated." At every sampling site, several of the heavy metal concentrations exceeded the elutriate test criteria to a depth of at least 5 feet. In 15 of the 20 sites, the elutriate test was exceeded to a depth of 10 feet.

Per Hall, Pullerits, Zollman, 1974, found concentrations of heavy metals, particularly lead and zinc, in quantities exceeding former criteria for open water disposal (0.005 by per cent of dry weight for lead and zinc) to depths of 70 to 80 feet below the sediment surface level. It is not known whether the natural background levels for these two metals could become available to organisms in the water column. The importance of this example is that it points out that some heavy metals may occur in natural background levels in certain geographic locations in quantities that exceed one or more standards established for toxicity criteria.

In general, this study has found that the upper five feet of sediment contain higher concentrations of heavy metal in the sediment analysis but do not always show the highest quantities of the same metal in the elutriate test. For example, at Site 1, Cu exceeds the elutriate test in only one core sample, No. 1-5 (see Appendix C, sediment sample tables). In the sediment samples for Site 1, the mg/kg ratio for Cu is greater at five of the other core samples; yet these test lower than Sample No. 1-5 in the elutriate test. A discussion of the probable cause of this inconsistency in correlation is contained in Section 5.1. The results of these analyses are significant, and any criteria

established for dredging to remove pollutants should be carefully evaluated in terms of the type of chemical analysis performed and the meanings of the analysis for biological considerations.

Baltimore Harbor has a surface area of approximately 34 square miles, or 950 million square feet. It is estimated that approximately one-half the Harbor's sediment surface area, some 475 million square feet, contains material that is either highly or moderately polluted. Dredging this area to a depth of ten feet would require the removal of about 176 million cubic yards of material. Even dredging to a depth of five feet would require the removal of 88 million cubic yards of material. This estimate of the volume that may be termed significantly polluted is based on the "Distribution of Toxic Zones" map, Figure 5-1, that indicates that approximately one-half of the Harbor's surface area is classified in the highly and moderately toxic zones.

The sample sites in this study were distributed fairly evenly throughout the entire Harbor, and as previously stated, material termed contaminated according to the elutriate test criteria was found at all sites and at various depths of the core samples. If the elutriate test results alone were used to determine contaminated sediments, then, the entire Harbor would be classified as contaminated because it exceeds the 1.5 times the overlying water concentration of the metals analyzed. Because dredging to this volume may well be not feasible, new standards for classifying degrees of pollution are needed. At present a recommendation would be to design a dredging program to remove effectively only the most highly contaminated sediment. Such new standards should identify the concentrations of heavy metals, hydrocarbons, PCB's, or other contaminants that exceed the established limits, classifying the material in question as "significantly or highly contaminated" as compared to samples containing lesser quantities of contaminants and classified as "low or slightly contaminated."

To determine the exact location and distribution of the zones of high concentrations of pollutants, additional sampling would be required in areas where sampling sites within this study did not extend, such as up into the creek areas and between the sampling sites within the Harbor. A determination could then be made of the specific areas of the Harbor containing sediments classified as "highly toxic" and that may be considered for dredging and removal. The classification of material would depend upon the establishment of a definition and standard that outlines the analysis techniques to be used and the levels or concentrations of measured contaminants to be considered as "high" or "low" toxicity.

### 6.3.2 Dredging Techniques

From studies conducted by the Corps of Engineers and others (see Appendix F), there is evidence that dredging can be accomplished with certain improved techniques and equipment that will greatly reduce extensive plumes or disturbance to the sediments and the release of contaminated materials into the water column. Newly developed dredging equipment, such as the Pneuma<sup>®</sup> Dredge, is reported to cause less disturbance to bottom sediments than other equipment traditionally employed in dredging. Modifications to older equipment, such as the use of silt curtains, have also been reported effective in reducing turbidity or sediment dispersal into the water column.

Assuming a dredging technique was used that reduced turbidity to an acceptable level, the problem of placement and site location must then be considered. There are basically four different methods of disposing of dredged spoils: open water disposal, creation of artificial habitat such as marshland, upland disposal, and diked disposal.

### 6.3.3 Open Water Disposal

Placement of the contaminated dredged spoils from Baltimore Harbor, defined by Maryland law as "the tidal portions of Patapsco River and its tributaries lying westward of a line extending from Rock Point in Anne Arundel County to North Point in Baltimore County," into open waters of the Chesapeake Bay is prohibited under the Annotated Code of Maryland, Article - Natural Resources Title 8, Subsection 16, 1975. The only other alternative for open water disposal of the Harbor sediments would be to place them in the ocean. Federal regulations and criteria, including those contained in Section 163 of the Marine Protection, Research, and Sanctuaries Act of 1972, and Section 404 of the Federal Water Pollution Control Act Amendments (P.L. 92-500), must be met for any disposal of material in navigable waters.

Ocean dumping of the Harbor dredged spoils would be subject to review by Federal agencies under the previously cited public laws and regulations, as well as State laws for whatever states' borders might be affected by off-shore ocean disposal. Because the purpose of the Marine Protection, Research, and Sanctuaries Act is to find means of disposal that will end

all ocean dumping, releasing Harbor spoils at sea is not considered to be an effective or feasible solution to the problem.

Reinforcing this conclusion is the distance the material from Baltimore Harbor would have to be transported. It is 130 nautical miles from the Harbor mouth to the entrance to Chesapeake Bay; and, of course, any ocean dumping would necessarily take place a considerable distance offshore. The logistics, hazards, economics, and political obstacles to such a means of disposal would be formidable.

#### 6.3.4 Creation of Artificial Habitat

There have been several projects and studies conducted in the use of dredged spoils to create new marsh areas or to fill in adjacent-to-land shallow water to create new upland sites (see Appendix F). While this method of using dredged material may be a worthwhile concept under certain circumstances and in particular geographic areas, it is not considered feasible as a disposal method for the contaminated Baltimore Harbor spoils.

Both artificial marsh and low-lying land created from dredged spoils are subject to runoff, tidal wash, and seepage that could transport the sediment fines and dissolved toxic materials from the deposited spoil into the surrounding water. There is, in short, probability of substantial environmental damage to the adjacent water column, to benthic communities, and to ground water. Before taking such action in the Chesapeake Bay, a specific site would have to be pre-selected and thoroughly evaluated for the possible environmental impact on aquatic habitat such as spawning sites, nursery grounds, shellfish beds, etc. Further, Maryland State law quoted previously specifically states that Baltimore Harbor spoil may be deposited only in "contained areas approved by the Department." Any proposed artificial habitat would have to be thoroughly studied to determine whether it qualified as a contained area.

### 6.3.5 Upland Disposal

The location, feasibility, and cost of upland disposal sites for contaminated dredged spoils has been studied by the Maryland Department of Transportation for a number of years. In the Environmental Impact Statement for the proposed I-95 Fort McHenry Tunnel in Baltimore Harbor, potential upland disposal sites for dredged material were identified. These sites consisted mainly of abandoned sand and gravel quarries. The largest site identified could contain 8 million cubic yards of material. The average site was 3 million cubic yards. In all, 12 potential sites were located within a 52-mile radius of Baltimore that could possibly contain a maximum of 41 million cubic yards of dredged material.

Some additional studies were completed to look for abandoned strip or deep mines in Western Maryland and West Virginia. The mines were considered as possible disposal sites, but the cost of hauling material from Baltimore Harbor to Western Maryland or West Virginia was considerable. It was estimated that it would cost approximately \$11.00 (1972 dollars) per cubic yard to remove the material from the Harbor, transport it by rail or truck, and place it in an abandoned mine. This did not include the cost of the land or any land reclamation costs.

In addition to the high cost associated with a long-distance haul for upland disposal, all land disposal sites have one potential common environmental impact. It is that the contaminated materials can leach out and enter nearby streams or be transferred into ground water supplies or aquifers. Therefore, a potential land disposal site must be thoroughly investigated for its location in a watershed and the danger of contamination of a stream, lake, or groundwater.

Material that is contaminated and cannot be disposed of in open water can be placed in land sites if the particular site is determined to be safe from the leaching or groundwater contamination potentials discussed above. However, upland site placement of the Baltimore Harbor material is not considered a feasible solution due to the large quantities involved. It will be recalled that removing one-half of the square footage of highly and moderately toxic material in the Harbor to a depth of 10 feet would involve some 176 million cubic yards of material. If all of the potential upland disposal sites within a 52-mile radius of Baltimore could be used, they could hold only 41 million cubic yards or 23% of the total quantity. Removal of only the highly toxic material to a depth of 10 feet involves 79 million cubic yards. Additional sites such as abandoned strip or deep mines where

environmental acceptability are unknown would have to be utilized. The only potential use of upland sites appears to be for relatively small quantities of spoil. If the spoil is highly contaminated, such as that in certain locations in the Harbor, exceptional effort would be required to prevent environmental damage.

#### 6.3.6 Diked Disposal

The use of a diked disposal area to contain material dredged from Baltimore Harbor and its approaches has been approved by the State of Maryland and the appropriate Federal agencies. Following application for the use of the Hart-Miller Islands site by the State in 1972, and following the filing of the appropriate environmental impact statement and numerous hearings, construction of this containment site is scheduled to begin in the near future. This method of spoil placement is the only feasible one at present in Maryland given both the practical limitations connected with upland disposal, creation of an artificial habitat, etc., and the legal limitations which prohibit open water disposal.

##### 6.3.6.1 Effectiveness of Diked Disposal

The effectiveness of diked disposal sites has been evaluated by a small number of investigators, all within the past few years and only for individual sites. Appendix M of the Dredge Disposal Study - San Francisco Bay and Estuary (see Appendix F) indicates that in diked disposal sites:

"Regulations set by The California Regional Water Quality Control Board on turbidity and settleable matter from dredged material containment areas can generally be met by providing adequate residence time in holding ponds. The possible release of heavy metals in the diked area effluent depends on many factors which make effluent quality predictions difficult, but it appears that a well-designed settling area will produce an effluent meeting realistic water quality requirements. However, in cases where specific effluent requirements are not being met, then a coagulation treatment system could be readily and inexpensively installed to upgrade the

"effluent to meet the requirements. A brief study of the Mare Island disposal site for dredged material indicated that metals were not being leached from the disposal area."

The Arthur D. Little, Incorporated study for the Army Engineer Waterways Experiment Station states: "Toxic pollutants can be released from confined disposal areas through seepage and through incorporation into food chains. An initial effort should be made to determine whether release of toxic pollutants is a problem."

The study also states:

"Most districts do not test for possible release of toxic pollutants from confined disposal areas, although testing of material to be dredged will be performed in the future according to regulatory practices. In the New Orleans District, no testing of possible release of toxic pollutants is performed unless a known toxic pollutant exists, as determined by previous testing of the material at the dredged site. In areas where mercury is known to be present, tests are performed continuously to determine the mercury concentration at the dredged site, disposal site, the spillway, and in the receiving waters near the disposal area. No detrimental impacts have been registered."

#### 6.3.7 Permanence of Removal

The overriding factor in considering the permanence of any potential corrective action is the reduction or elimination of the contaminants now being discharged into the Harbor. In-place pollutants could be physically removed, but any effectiveness achieved by this action would soon be negated by new pollutant loadings from community and industrial discharge sources.

Section 4.3 of this report discusses former studies which report quantities of pollutants discharged into Baltimore Harbor in addition to the NPDES permit authorizations. The present rate of discharge of pollutants to Baltimore Harbor is unknown for the quantities of heavy metals and other pollutants measured in this study; but from the data reviewed, it is known that significant quantities of metals and total suspended solids are presently being discharged each day. Helz (1976), for example, reports that approximately 27 thousand metric tons of heavy metals are entering the Harbor each year from all sources; Quirk, Lawler, and Matusky (1973) list approximately 86 tons per day of all pollutants, 72% of which are metals. A partial summary of NPDES permit authorizations for January 1977 indicates:

Domestic -- Total suspended solids of 276,816 lbs/day as a weekly average from 47 major sources out of 690 total reported.

Industrial - Total suspended solids of 879,372 lbs/day maximum from 65 industries out of a total of 184 reported.  
- Total metals of 238,378 lbs/day maximum from 9 major industries out of a total of 184 reported.

The areas considered to be the most highly contaminated are also the areas receiving both community and industrial discharges at the present time, e.g., Northwest Branch from the Jones Falls Discharge and adjacent plants; and Colgate Creek, Bear Creek, Curtis Bay, and the Inner Harbor from their individual watershed stream flows, industrial sites, and sewage treatment plants located on these creek and harbor areas.

Only after these discharge loadings have been eliminated could removal of the in-place pollutants be considered a permanent action.

#### 6.4 LEAVING UNDISTURBED

To leave the Baltimore Harbor sediments undisturbed would not be a corrective action in the same sense as blanket, inactivate, or remove, but it is a viable alternative to be considered under the terms of this study -- "give an analysis of the environmental effect of the polluted sediment and/or why it is a problem (i. e., can it be left alone; is it part of an area to be dredged; is it adversely affecting water quality and water use? )."

The findings of this study and others have shown that the benthos within the Harbor are adversely affected by the in-place pollutants. The pelagic and planktonic biota are also stressed but to a lesser degree. Leaving the pollutants in place, undisturbed, will not alleviate the present damage to the biota, nor will it help future improvement while the pollutants remain in their present concentrations and distribution. However, any other potential action that could be taken, such as removal of the polluted sediments by dredging, will likewise be ineffective as long as new pollutant loads are being discharged into the Harbor.

The alternative action of leaving the polluted sediment undisturbed is, therefore, the only practical action that can be considered at this time under the present conditions. The feasibility of this action is discussed in Section 7.4 which follows.

7.0      FEASIBILITY AND COSTS OF POTENTIAL  
CORRECTIVE ACTIONS

All potential corrective actions contain within them elements of trade-offs which need to be weighed carefully before a realistic course can be recommended. In particular, any preferred corrective action to be applied to Baltimore Harbor must be selected with due regard to the fact that the Harbor is a major U. S. port. In 1975, there were more than 4,000 ship arrivals and departures: being a shallow body of water, many vessels maneuver in the Harbor with little or no bottom clearance. Within the Harbor, many industrial facilities, ranging from steel mills and electric generating power plants to small manufacturing firms, use the waters for intake cooling, discharges and transport of equipment, fuel and goods. Wharves and other facilities contribute significantly to the oils, greases, and detritus to be found floating in the Harbor eventually to be lodged in the sediments. It is in this environment that the possible corrective actions which follow have been evaluated for feasibility.

## 7.1 BLANKETING

Blanketing the polluted sediments in the Harbor is not considered to be a practical method for overcoming the problems associated with in-place pollutants in Baltimore Harbor. The constant volume of ship and barge traffic -- including anchoring and maneuvering of large vessels -- and related water activities would soon tear or displace any plastic film extruded over the surface of the bottom of the Harbor. The process of blanketing with a chemical composition that forms a plastic film in place under water is relatively new, and, to our knowledge, has only been used on sediments to decrease turbidity for underwater ship repair and other marine work. Its applicability to large or extensive areas and its durability for long periods of time are unknown.

The cost of the blanketing pilot tests performed in 1970 by the U. S. Navy was approximately \$1.00 per square foot. The Navy did not carry this project beyond the experimental phase to see if the blanket was effective in reducing turbidity for divers working on the ocean floor. The duration of time that this blanket will stay in place and its overall effectiveness is unknown. Accordingly, due to the complexities of attempting to maintain a plastic film intact in a working harbor and the lack of sufficient data on the effectiveness of the blanket for an extended period of time, this approach is not considered feasible.

## 7.2        INACTIVATING

The potential for inactivating the pollutants within the sediments of Baltimore Harbor is not considered a feasible action due to the complexities of dealing with multiple chemical compounds in various forms and under variable toxic conditions. As there are no known methods or pilot programs that have attempted this type of inactivation of polluted sediment by chemical neutralization or reactive treatment, this method must be considered infeasible at the present time.

### 7.3 REMOVING

Removing contaminated sediments by dredging is a proven method that has been successfully accomplished in many harbors and waterways for many years. In dredging operations, however, there is necessarily some disturbance to the sediments that creates turbidity in the adjacent area of the dredge equipment, even under the best of conditions. Although there have been objections raised to dredging because of the danger of releasing contaminants into the water column, dredging is an accepted method for removing unwanted spoil. It is an ongoing activity in Baltimore Harbor and approaches for purposes of maintenance of channels, approaches, slips and berths. Thus, removal of the polluted sediments in Baltimore Harbor should, if properly done, be slightly, if any more, disturbing to the water column than present activities. In addition, large ships' passage, storms, and tidal action also cause disturbances and increased turbidity in shallow areas, such as in Baltimore Harbor, whose bottom is composed of fine-grained particles that make up the sediment layers. The contaminants released to the water column through these actions seem to remain within the Harbor itself and do not appear to affect adversely the health of the Harbor's water or the health of the biota in the Chesapeake Bay (see discussion in Section 5.3).

Therefore, it is concluded that removal of the in-place pollutants by dredging can effectively be accomplished without extensive or permanent damage to the waters of the Harbor or Bay.

#### 7.3.1 Feasibility

Although dredging can remove polluted sediments, the feasibility of applying this approach to the problem studied here can be seriously questioned because of the huge volumes involved, costs, and the need to provide a suitable repository for the spoil. If the results of the bioassay and previous findings on the community structure and diversity of benthic macro-invertebrates are used to determine the zones of toxicity within the Harbor, it will be seen from Figure 5-1 that approximately one-half (17 square miles) of the Harbor is classified as highly and moderately toxic. Dredging an area of this size to a depth of ten feet would require the removal of about 176 million cubic yards of material. While this can be done with dredging equipment available

today, placement of this huge volume of contaminated material in a suitable location is not possible under present laws and available site locations.

As a final note to the approaches reviewed above, but with particular import to dredging, the overriding consideration in all three instances is that unless the pollutant loads now being discharged into the Harbor are eliminated or reduced drastically, no approach will have lasting effect. In addition, the question of costs aside, dredging is feasible only when an environmentally suitable disposal site can be made available.

### 7.3.2 Costs of Removal

The costs of dredging and the placement of the spoil vary from one location to another and for different sized jobs. Normally, the larger the quantity to be dredged, the less the cost per cubic yard will be because the contractor must mobilize his equipment regardless of the size of the operation. The direct cost for dredging alone is not the sole consideration, however, because with the prohibition of open water disposal of Baltimore Harbor materials in the Chesapeake Bay, dredged material must be disposed of either within the Harbor itself or be placed in a diked disposal or upland site. Transport costs and costs of site acquisition, preparation, and construction must be included.

The most recent contract (1977) let by the Corps of Engineers for dredging the Craighill-Cutoff Channel Angle was for \$0.91 per cubic yard based on a quantity of 685,300 cubic yards and a cost of \$12,000 to mobilize and demobilize the dredging equipment. It was specified that the material be placed in the open water of the Harbor at the disposal site off Rock Point in the mouth of the Patapsco River. This type of dredge and placement is the most inexpensive since the material is placed in open water not far from the dredge site.

Unit costs for dredging and placement based on the ratio of the Engineering News Record Construction Cost Index (December 1976) for utilization of a hopper dredge are as follows:

$$\begin{aligned} \text{Total Unit Cost} &= \text{cutting and offloading costs } (.44/\text{cu yd}) \\ &+ \text{transportation costs } (0.0497/\text{cu yd/mi}). \end{aligned}$$

Utilizing this formula, it would cost over 74 million dollars to remove, transport, and place 79 million cubic yards of highly toxic material into a diked disposal site ten miles from the dredging site. The cost incurred in the construction of a diked disposal site such as Hart-Miller Island is estimated to be \$0.69 per cubic yard of placed storage or a total of approximately 54.5 million dollars for holding the 79 million cubic yards.

Cost Summary:

|                                                                     |                      |
|---------------------------------------------------------------------|----------------------|
| Cutting and offloading --                                           |                      |
| 79,000,000 yd <sup>3</sup> x \$0.44/yd <sup>3</sup> =               | \$ 34,760,000        |
| Transportation --                                                   |                      |
| 79,000,000 yd <sup>3</sup> x \$0.0497/yd <sup>3</sup> /mi x 10 mi = | \$ 39,263,000        |
| Construction of diked disposal area --                              |                      |
| 79,000,000 yd <sup>3</sup> x \$0.69/yd <sup>3</sup> =               | <u>\$ 54,510,000</u> |
| Total (est.)                                                        | \$128,533,000        |

Total costs for this quantity (79 million cubic yards) would thus approximate a total expenditure of 128.5 million dollars to dredge, transport, place, and construct the diked disposal site for its placement. If, as is usual, the diked area were located in shallow water, the cost of creating a channel to reach it would need to be included.

Before the feasibility of leaving the polluted sediments undisturbed can be fully evaluated, consideration must be given to the present and future effects of these sediments on benthic species and on the water column insofar as it affects pelagic species and other users of the Harbor waters. Through the analyses of some of the known pollutants in the sediment and water and from the bioassay, this study, like others, found that in-place pollutants are causing damage to the benthic macro-invertebrates and the bottom-dwelling and -feeding fish. The damage to the pelagic fish and planktonic organisms is less but also measurable. It is not known if the damage to the pelagic species is caused by pollutants from incoming discharges, by the release of pollutants from the sediments, or by a combination of both.

If the polluted sediments are left in place, undisturbed, we may expect that:

- ° Some of the contaminants will continue to be released slowly from sediments into the water column and, with high dilution, into the Chesapeake Bay system.
- ° There will be sporadic increases in the rate of release into the water column as the result of storms, ship traffic, or other transient events.
- ° There will be continued stress to the benthos; but this stress is expected to decrease with time as the sources of incoming pollutants are reduced or eliminated.
- ° The damage to water quality and the pelagic species will also continue, but should decrease as incoming pollutants are decreased.
- ° Since there is less damage occurring to the pelagic species than to the benthic and since it is possible that some of the present damage may be caused from incoming pollutants rather than the in-place pollutants, the recovery to the water quality and pelagic species should be more rapid than for the benthos.

- The in-place pollutants will, in time, be covered either partially or completely with clean sediments as incoming pollutant loads are reduced or eliminated

Leaving the sediment undisturbed is, therefore, a feasible alternative from the standpoint that the damage the in-place pollutants have caused or will cause to the benthos has already occurred and should not increase. The effects of the in-place pollutants should be reduced by the slow accumulation of cleaner sediments resulting from the elimination of incoming loads of new pollutants to the point that, in time, the benthos and water quality will slowly recover.

The cost of leaving the sediment undisturbed is difficult to measure as there is an intrinsic value of clean water to users for both industrial and recreational purposes. From the point of view of commercial fishing, there is some cost associated with the reduction of spawning sites and nursery grounds for finfish, crabs, clams and oysters, and the benthic and planktonic species that are in the food chain. However, Baltimore Harbor has not served as an important spawning site for commercially important species nor has it had good nursery ground habitat for many years, possibly since the early 1900's. Recovery of this habitat, while important, is minor compared to the rest of the Chesapeake Bay, and will always be of less significance due to the Harbor's normal activity of heavy industry, related water uses by the industrial complex, and channel dredging.

No other cost factors that can be measured in dollars can be applied to this alternative action, but the cost of this course of action will not increase but rather should decrease in time as additional pollutant loads are eliminated.

## 8.0 CONCLUSIONS AND RECOMMENDATIONS

### 8.1 CONCLUSIONS

1. The in-place pollutants in Baltimore Harbor are distributed heterogeneously throughout the Harbor sediments with a number of highly localized concentrations occurring in certain areas. This conclusion is based on the results of this study and others and is supported by the community structure diversity and distribution of finfish and benthic organisms.
2. The depths to which the pollutants extend is unknown, but core samples have shown that all heavy metals examined are to be found at depths up to 10 feet in quantities that exceed the elutriate test standard of 1.5 times the overlying water. There is a general tendency for the quantities of all pollutants to decrease with depth below five feet, but several sample sites contain pollutants in equal or greater quantity in the seven-to-ten-foot depths.
3. The results of the elutriate test, the bioassay, and the sediment and interstitial water analyses do not correlate well enough with each other to indicate the sites of highest pollution levels. The sites that contain some of the highest quantities of heavy metals in the sediments tested low in the elutriate test. Conversely, some of the samples testing the highest in the elutriate test contain relatively low quantities of the same metal in the sediment. The results of the bioassay correlate to some degree with the bulk sediment and the PCB analyses but correlate less with the results of the elutriate and the interstitial water analyses.
4. The results of this study correlate very closely, for the same site locations, with the high and low concentrations of heavy metals as reported in the 1974 Region III EPA Study, "Distribution of Metals in Baltimore Harbor Sediments" by Villa and Johnson.
5. The result of the bioassay and the observed community structure and diversity of benthic macro-invertebrates correlate with the gross toxicity of the sediments to reflect high, moderate, low, and slight zones of toxicity within the Harbor. On this basis, approximately one-half the area of the Harbor is classified in the high and moderate toxic zones.

6. The sites containing high levels of PCB's and hexane extracts correlate moderately well with the sites considered as highly toxic for benthic macro-invertebrates and the bottom-dwelling and feeding fish. It appears that these in-place pollutants are major factors in causing stress to these species.
7. The results of the elutriate test indicate that the heavy metals contained in the sediments may have a significant effect on the overlying water column when the sediments are mixed or dispersed in the water. The residence time that these metals remain in the water column and the percent removed from the sediment are unknown.
8. The community structure, diversity, and distribution of pelagic fish and phytoplankton bear no relation to the zones of toxicity such as those of the benthic macro-invertebrates and bottom-dwelling fish.
9. The community structure, diversity, and distribution of pelagic fish and planktonic organisms may be affected by the pollutants from industrial and community discharges as well as from those released from the in-place sediments. It was not possible to assess the relative importance of these two sources of pollution.
10. It was not possible to determine the quantities of the same pollutants examined in this study that are presently being discharged into the Harbor, but it is known from the investigation of NPDES permit data that industrial and community discharges contain significant quantities of heavy metals and suspended solids. The last total inventory of pollutants discharged to the Harbor (1973) indicates that some 86 tons of heavy metals and toxic chemicals were being discharged into the Harbor each day.
11. In a recent review, Helz (1976) estimated that a relatively small percentage of the heavy metals entering the Harbor remain in the Harbor. The rates and routes of removal and the form of the metals leaving the Harbor and entering the Chesapeake Bay are unknown, but the mechanism by which this occurs may be significant to the upper estuary which is a nursery region.
12. Despite the reported high-removal rate of heavy metals from Baltimore Harbor, the Harbor acts as a repository for pollutants

as evidenced by the concentration of heavy metals found at all depths of the core samples and the high concentrations of certain metals to be found in localized deposits.

13. Of the three possible corrective measures requiring action -- blanketing, inactivating, removing -- only the last, dredging the Harbor bottom and placing the polluted sediment elsewhere, is a practical method if certain factors such as cost and the location and type of disposal sites are not considered. This conclusion is dictated by practical considerations of the uses of the Harbor and the state-of-the-art in large scale blanketing and inactivation techniques.
14. All sites and all depths of sampling contained concentrations of heavy metals that exceed the elutriate test standard indicating the entire Harbor is contaminated to depths of at least 10 feet. Also by 1973 EPA interstitial water standard for levels of heavy metals hazardous to aquatic life, the entire Harbor would be classified contaminated. A designation of those areas that are highly, moderately, or slightly polluted is difficult to make by means of these analytical techniques. If partial removal of the contaminated sediments is to be undertaken to dredge only those areas that contain the highest concentrations of pollutants, new or additional criteria would need to be established to describe the pollutorial characteristics of the sediments so that priority judgments could be made.
15. Maryland State law prohibits the placing of any material dredged from Baltimore Harbor in the open waters of the Chesapeake Bay. The law further requires that "the spoil may be redeposited in contained areas approved by the Department." The only presently approved contained area, other than upland disposal sites, is the Hart-Miller Diked Disposal Site. Therefore, any dredged material from the Harbor would have to be placed in an upland site, in the future Hart-Miller Disposal Site, or in a similar site yet to be designated.
16. A review of potential upland disposal sites within a 52-mile radius of Baltimore found that there is a maximum containment potential of some 41 million cubic yards of material. Even partial removal of the highly contaminated sediments and placement in upland disposal sites would exceed the total potential capacities of these sites.
17. The influx of new pollutant loads, now being discharged into the Harbor from industrial and community sources, would eventually negate the benefit achieved by any corrective action. The pollutants

now being discharged into the Harbor would soon begin to replace those removed, blanketed, or inactivated. Therefore, a prerequisite to any permanent action is the implementation of the provisions of P. L. 92-500 and a cessation or drastic reduction of the current influx of pollutants to the Harbor waters.

18. Given conclusion number 17 and given the difficulties and obstacles faced by any active solution to the problem of in-place pollutants, we conclude that leaving the polluted sediments undisturbed is the most realistic course to take at the present time. We conclude that this course will continue to be the most realistic one until such a date that the pollutant discharge loading into the Harbor is eliminated or drastically reduced.

This date, according to the provisions of Sec. 101(a)(1), P. L. 92-500, is 1985. During the interim, we can anticipate a gradual improvement in the quality of the water column as the provisions of Sec. 402, "National Pollutant Discharge Elimination System" (NPDES) are met; and, through natural processes, a partial improvement in the surface layer sediments as deposition of clean runoff sediments occur from stream sources.

## 8.2 RECOMMENDATIONS

1. The in-place polluted sediments in Baltimore Harbor be left undisturbed. (Note: This recommendation applies only to the nature of the problem posed by this study. It is not intended to apply to any present or planned activity such as channel or ship berth maintenance and improvement dredging.)
2. These sediments be left undisturbed at least until such time as the current influx of pollutants is eliminated or reduced sufficiently so as to not negate any corrective action.
3. Removing the in-place pollutants by dredging is recommended only following a determination that the natural recovery that might be expected from the inflow of uncontaminated sediments from the river and stream sources is not correcting the present problems. Once the discharge of toxic material has been stopped, a slow recovery of the benthos and of the water column should result from a partial, if not full, blanketing effect of uncontaminated sediments from natural sources covering the in-place pollutants.
4. A re-evaluation be made at the time the influx is reduced or eliminated (i.e., 1985) to determine whether or not the deposition of clean sediments is occurring at a rate commensurate with the objectives of P.L. 92-500. If not, the preferred method for meeting the provisions of Sec. 115 is the removal of the highly and moderately toxic polluted areas by means of dredging and the placing of the dredged material in approved diked disposal sites. This recommendation presumes that no new, innovative means for otherwise dealing with the problem is developed in the interim.
5. If removal of the in-place pollutants becomes a necessity, only the areas classified as highly and moderately toxic be considered. If a priority need be established and only partial removal can be accomplished for economic considerations, the areas of high toxicity should be given first priority. Any dredging in the areas of high toxicity should be done by dredging methods and equipment that create a minimum of disturbance to the sediments, thus reducing turbidity and release of the materials into the water column.
6. A more thorough analysis and quantification of the pollutants presently being discharged into the Harbor and determination of the pathways of

transport, deposition, re-release, and movement into the biota should be accomplished.

7. The scheduled channel improvement in Baltimore Harbor and the scheduled Hart-Miller disposal site construction and activation be carefully followed by means of a planned monitoring program to determine the actual effect on the biota and other environmental impacts. The dredging, due to begin shortly, offers a unique opportunity to obtain, empirically, information on the actual stress caused by large-scale dredging in the Harbor and, given the uncertainties normally associated with deductive methods, appears to be the one approach certain to yield positive answers quickly. While this recommendation is not within the scope of this study, it is considered appropriate and particularly germane in light of the scheduled large scale dredging program planned for the Harbor and its approaches.